15 ENERGY EFFICIENCY AND RENEWABLE ENERGY

The Coming Energy-Efficiency and Renewable-Energy Revolution

Energy experts Hunter and Amory Lovins (Guest Essay, p. 361) have built a large, passively heated, superinsulated, partially earth-sheltered home and office in Snowmass, Colorado (Figure 15-1), where winter temperatures can drop to –40°C (–40°F).

This structure, which also houses the research center for the Rocky Mountain Institute, an office used by 40 people, gets 99% of its space and water heating and 95% of its daytime lighting from the sun. It uses one-tenth the usual amount of electricity for a structure of its size.

Today's superinsulating windows mean that a house can have large numbers of windows without much heat loss in cold weather or heat gain in hot weather. Thinner insulation material now being developed will allow roofs and walls to be insulated far better than in today's best superinsulated houses.

A small but growing number of people in developed and developing countries are getting their electricity from *solar cells* that convert sunlight directly into electricity. They can be attached like shingles to a roof or applied to window glass as a coating. Solar-cell prices are high but are falling rapidly.

Many scientists and executives of oil and automobile companies believe we are in the beginning stages of a *solar-hydrogen revolution*. Electricity produced by large banks of solar cells or farms of wind turbines could be passed through water to make hydrogen gas (H_2), which could be used to fuel vehicles, industries, and buildings. Another solution is to burn hydrogen in energy-efficient *fuel cells* that produce electricity to run cars and heat buildings and water.

Burning hydrogen produces water vapor, small amounts of controllable nitrogen oxides, and no carbon dioxide. Thus, shifting to hydrogen as our primary energy resource during the 21st century would eliminate most of the world's air pollution and greatly slow projected global warming.

These are only a few of the components of the *energy-efficiency and renewable-energy revolution* that many analysts believe will help us make the transition to more sustainable societies over the next 40–50 years.

Figure 15-1 The Rocky Mountain Institute in Colorado. This facility is a home and a center for the study of energy efficiency and sustainable use of energy and other resources. It is also an example of energy-efficient passive solar design. (Robert Millman/Rocky Mountain Institute)

If the United States wants to save a lot of oil and money and increase national security, there are two simple ways to do it: Stop driving Petropigs and stop living in energy sieves.

AMORY B. LOVINS

This chapter addresses the following questions:

- What are the advantages and disadvantages of improving energy efficiency?
- What are the advantages and disadvantages of using solar energy to heat buildings and water and to produce electricity?
- What are the advantages and disadvantages of using flowing water and solar energy stored as heat in water to produce electricity?
- What are the advantages and disadvantages of using wind to produce electricity?
- What are the advantages and disadvantages of burning plant material (biomass) to heat buildings and water, produce electricity, and propel vehicles (biofuels)?
- What are the advantages and disadvantages of producing hydrogen gas and using it to produce electricity, heat buildings and water, and propel vehicles?
- What are the advantages and disadvantages of extracting heat from the earth's interior (geothermal energy)?
- What are the advantages and disadvantages of using smaller, decentralized micropower sources to heat buildings and water, produce electricity, and propel vehicles?
- How can we make a transition to a more sustainable energy future?

15-1 THE IMPORTANCE OF IMPROVING ENERGY EFFICIENCY

What Is Energy Efficiency? Doing More with Less **Energy efficiency** is the percentage of total energy input into an energy conversion device or system that does useful work and is not converted to low-quality, essentially useless heat. Improving the energy efficiency of a car motor, home heating system, or other energy conversion device involves using less energy to do more useful work.

You may be surprised to learn that *84% of all commercial energy used in the United States is wasted* (Figure 15-2). About 41% of this energy is wasted automatically because of the degradation of energy quality imposed by the second law of energy (Section 3-7, p. 65). However, about 43% is wasted unnecessarily, mostly by **(1)** using fuel-wasting motor vehicles, furnaces, and other devices

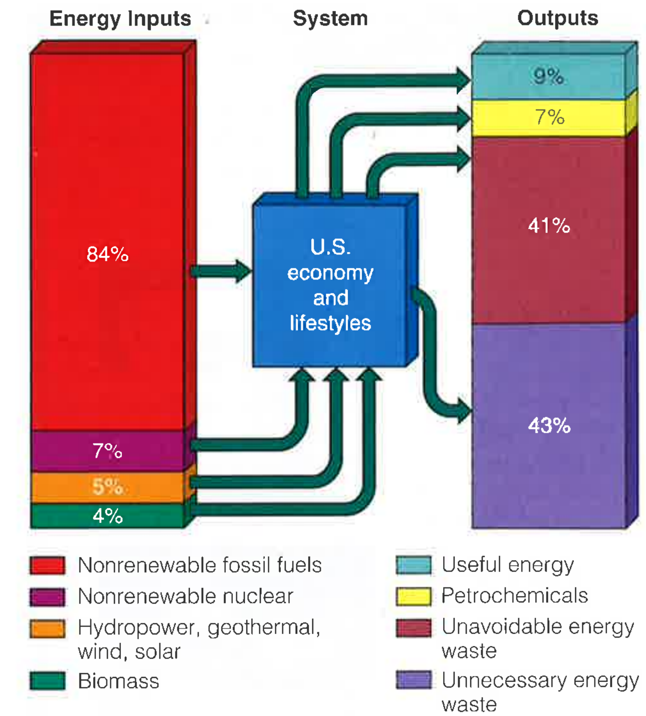


Figure 15-2 Flow of commercial energy through the U.S. economy. Note that only 16% of all commercial energy used in the United States ends up performing useful tasks or being converted to petrochemicals; the rest is either automatically and unavoidably wasted because of the second law of energy (41%) or wasted unnecessarily (43%).

and **(2)** by living and working in leaky, poorly insulated, poorly designed buildings (Guest Essay, p. 361).

According to the Department of Energy, the United States unnecessarily wastes as much energy as two-thirds of the world's population consumes. Improvements in energy efficiency since the OPEC oil embargo in 1973 have cut U.S. energy bills by $275 billion a year. However, unnecessary energy waste still costs the United States about $300 billion per year (an average of $570,000 per minute)—more than the $271 billion military budget in 2000.

Other developed countries also waste large amounts of energy, but many such as Japan, Germany, Sweden, and Denmark are about twice as energy-efficient as the United States. However, the world's most energy-inefficient countries are in the developing world. Reducing energy waste has a number of economic and environmental advantages (Figure 15-3).

The energy conversion devices we use vary in their energy efficiencies (Figure 15-4). We can save energy and money by buying more energy-efficient cars, lighting, heating systems, water heaters, air conditioners, and appliances. Some energy-efficient models may cost more initially, but in the long run they usually save money by having a lower **life cycle cost**: initial cost plus lifetime operating costs.

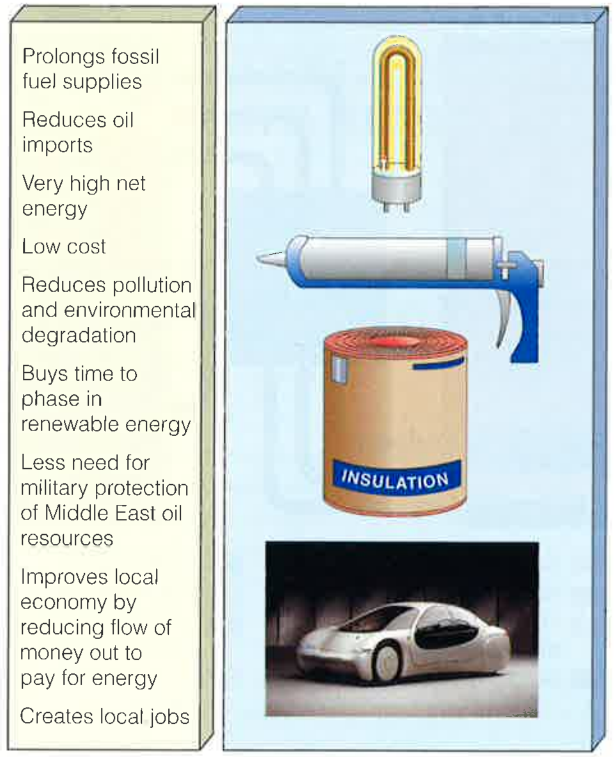


Figure 15-3 Advantages of reducing energy waste. Global improvements in energy efficiency could save the world about $1 trillion per year

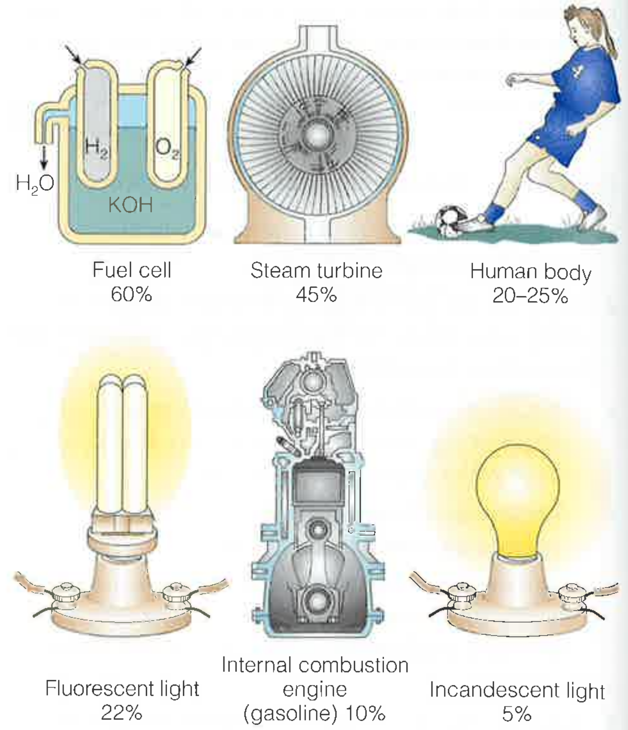


Figure 15-4 Energy efficiency of some common energy conversion devices.

The net energy efficiency of the entire energy delivery process for a space heater, water heater, or car is determined by the efficiency of each step in the energy conversion process. For example, the sequence of energy-using (and energy-wasting) steps involved in using electricity produced from fossil or nuclear fuels is

Extraction ⟶ Transportation ⟶ Processing ⟶
Transportation to power plant ⟶ Electric generation ⟶
Transmission ⟶ End use

Figure 15-5 shows the net energy efficiency for heating two well-insulated homes: **(1)** one with electricity produced at a nuclear power plant, transported by wire to the home, and converted to heat (electric resistance heating), and **(2)** the other heated passively, with an input of direct solar energy through high-efficiency windows facing the sun, with heat stored in heat-absorbing materials for slow release.

This analysis shows that the process of **(1)** converting the high-quality energy in nuclear fuel to high-quality heat at several thousand degrees in the power plant, **(2)** converting this heat to high-quality electricity, **(3)** transmitting the electricity to users, and **(4)** using the electricity to provide low-quality heat for warming a house to only about 20°C (68°F) is very wasteful of high-quality energy (Figure 3-11, p. 59). Burning coal or any fossil fuel at a power plant to supply electricity for heating water or space is also inefficient. It is much less wasteful to **(1)** collect solar energy from the environment, **(2)** store the resulting heat in heat-absorbing materials, and, **(3)** if necessary, use a small backup heating system to raise its temperature slightly to provide space heating or household hot water.

Figure 15-5 shows that one way to waste less energy (and money) is not using high-quality energy to do a job that can be done with lower-quality energy (Figure 3-11, p. 59). This helps explain why using electricity to heat a house (resistance heating) costs about three times more per unit of energy than using a heat pump (useful in warm to moderate climates only) and about twice as much as heating with oil or with an efficient natural gas furnace.

Perhaps the three least efficient energy-using devices in widespread use today are **(1)** incandescent light bulbs (which waste 95% of the energy input), **(2)** vehicles with internal combustion engines (which waste 86–90% of the energy in their fuel), and **(3)** nuclear power plants producing electricity for space heating or water heating (which waste 86% of the energy in their nuclear fuel, and probably 92% when the energy needed to deal with radioactive wastes and

GUEST ESSAY

Technology Is the Answer (But What Was the Question?)

Amory B. Lovins

Physicist and energy consultant Amory B. Lovins is one of the world's most respected experts on energy strategy. In 1989, he received the Delphi Prize for environmental work; in 1990 the Wall Street Journal *named him one of the 39 people most likely to change the course of business in the 1990s. He is research director at Rocky Mountain Institute, a nonprofit resource policy center that he and his wife, Hunter, founded in Snowmass, Colorado, in 1982. He has served as a consultant to more than 200 utilities, private industries, and international organizations, and to many national, state, and local governments. He is active in energy affairs in more than 35 countries and has published several hundred papers and a dozen books on energy strategies and policies.*

It is fashionable to suppose that we're running out of energy and ask how can we get more of it. However, the more important questions are **(1)** How much energy do we need and **(2)** What are the cheapest and least environmentally harmful ways to meet these needs?

How much energy it takes to make steel, run a car, or keep ourselves comfortable in our houses depends on how cleverly we use energy. It is now cheaper, for example, to double the efficiency of most industrial electric motor drive systems than to fuel existing power plants to make electricity. (Just this one saving can more than replace the entire U.S. nuclear power program.) We know how to make lights five times as efficient as those currently in use and how to make household appliances that give us the same work as now but use one-fifth as much energy (saving money in the process).

Ten automakers have made good-sized, peppy, safe prototype cars averaging 29–59 kilometers per liter (67–138 miles per gallon), and within a decade automakers could have cars getting 64–128 kpl (150–300 mpg) on the road if consumers demanded such cars. We know today how to make new buildings (and many old ones) so heat-tight (but still well ventilated) that they need essentially no outside energy to maintain comfort year-round, even in severe climates. In fact, I live and work in one [Figure 15-1].

These energy-saving measures are all cheaper than going out and getting more energy. However, the old view of the energy problem included a worse mistake than forgetting to ask how much energy we needed: It sought more energy, in any form, from any source, at any price, as if all kinds of energy were alike.

Just as there are different kinds of food, so there are many different forms of energy whose different prices and qualities suit them to different uses [Figure 3-11, p. 59]. After all, there is no demand for energy as such; nobody wants raw kilowatt-hours or barrels of sticky black goo. People instead want energy services: comfort, light, mobility, hot showers, cold beverages, and the ability to cook food and make cement. In developing energy resources we should start by asking, "What tasks do we want energy for, and what amount, type, and source of energy will do each task most cheaply?"

Electricity is a particularly high-quality, expensive form of energy. An average kilowatt-hour delivered in the United States in 1999 was priced at about 6.7¢, equivalent to buying the heat content of oil costing $111 per barrel—over three times the average world price of crude oil in 2000. No new nuclear plants are being built in the United States (and only a few are being built in other parts of the world). One reason is that the average cost of electricity from the last nuclear power plant built in the United States is about 13.5¢ per kilowatt-hour, equivalent on a heat basis to buying oil at about $216 per barrel.

Such costly energy might be worthwhile if it were used only for the premium tasks that need it, such as lights, motors, electronics, and smelters. However, those special uses—only 8% of all delivered U.S. energy needs—are already met twice over by today's power stations. Two-fifths of the electricity used in the United States is for uneconomic, low-grade uses such as water heating, space heating, and air conditioning. Yet no matter how efficiently we use electricity (even with heat pumps), we can never get our money's worth on these applications.

Thus, *supplying more electricity is irrelevant to the energy problem we have*. Even though electricity accounts for almost all the federal energy research-and-development budget and at least half the national energy investment, it is the wrong kind of energy to meet the nation's needs economically. Arguing about what kind of new power station to build—coal, nuclear, or solar—is like shopping for the best buy in antique Chippendale chairs to burn in your stove, or for expensive brandy to put in your car's gas tank.

The real question is, "What is the cheapest way to do low-temperature heating and cooling?" The answer is weather-stripping, insulation, heat exchangers, greenhouses, superwindows (which have as much insulating value as the outside wall of a typical house), roof overhangs, trees, and so on. These measures generally cost about 0.5¢–2¢ per kilowatt-hour, the lowest-cost way by far to supply energy.

If we need more electricity, we should get it from the cheapest sources first. In approximate order of increasing price, these include:

- Converting to efficient lighting equipment. This would save the United States electricity equal to the output of 120 large power plants, plus $30 billion a year in fuel and maintenance costs.
- Using more efficient electric motors to save up to half the energy used by motor systems. This would save

(continued)

GUEST ESSAY (continued)

electricity equal to the output of another 150 large power plants and repay the cost in about a year.

- Displacing the electricity now used for water heating and for space heating and cooling with good architecture, weatherization, insulation, and mostly passive solar techniques.
- Improving the energy efficiency of appliances, smelters, and the like.

Just these four measures can quadruple U.S. electrical efficiency, making it possible to run today's economy with no changes in lifestyles and using no power plants, whether old or new or fueled with oil, gas, coal, uranium, or solar energy. We would need only the present hydroelectric capacity, readily available small-scale hydroelectric projects, and a modest amount of wind power.

If we still wanted more electricity, the next cheapest sources would include **(1)** cogenerating electricity and heat in industrial plants and power plants, **(2)** using low-temperature heat engines run by industrial waste heat or by solar ponds, **(3)** filling empty turbine bays and upgrading equipment in existing big dams, **(4)** using modern wind machines or small-scale hydroelectric turbines in good sites, **(5)** using combined-cycle natural-gas turbines, and perhaps **(6)** using recently developed more efficient solar cells when their price is reduced by mass production.

It is only after we have exhausted all these cheaper opportunities that we would even consider building a new central power station of any kind—the slowest and costliest known way to get more electricity (or to save oil).

To emphasize the importance of starting with energy end uses rather than energy sources, consider a story from France. In the mid-1970s, energy conservation planners in the French government found that their biggest need for energy was to heat buildings and that even with good heat pumps, electricity would be the costliest way to do this. So they had a fight with their government-owned and -run utility company; they won, and electric heating was supposed to be discouraged or even phased out because it was so wasteful of money and fuel.

Meanwhile, down the street, the energy supply planners (who were far more numerous and influential in the French government) said, "Look at all that nasty imported oil coming into our country. We must replace that oil with some other source of energy. Voilà! Nuclear reactors can give us energy, so we'll build them all over the country." However, they paid little attention to who would use that extra energy and no attention to relative prices.

Thus, these two groups of the French energy establishment went on with their respective solutions to two different, indeed contradictory, French energy problems: *more energy of any kind* versus *the right kind to do each task in the most inexpensive way*. It was only in 1979 that these conflicting perceptions collided. The supply-side planners suddenly realized that the only thing they would be able to sell all that nuclear electricity for would be electric heating, which they had just agreed not to do.

Every industrial country is in this embarrassing position. Supply-oriented planners think the problem boils down to whether to build coal or nuclear power stations (or both). Energy-use planners realize that *no* kind of new power station can be an economic way to meet the needs for using electricity to provide low- and high-temperature heat and for the vehicular liquid fuels that are 92% of our energy problem.

So if we want to provide energy services at the lowest cost, we need to begin by determining what we need the energy for!

Critical Thinking

1. The author argues that building more nuclear, coal, or other electrical power plants to supply electricity for the United States is unnecessary and wasteful of energy and money. List your reasons for agreeing or disagreeing with this viewpoint.

2. Explain why you agree or disagree that increasing the supply of energy, instead of improving energy efficiency, is the wrong answer to our energy problems.

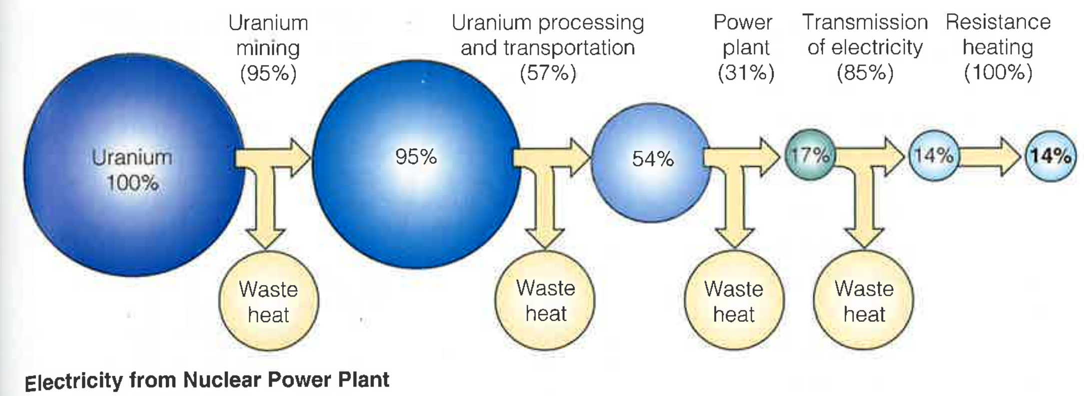
retired nuclear plants is included). Energy experts call for us to replace these devices or greatly improve their energy efficiency over the next few decades.

Coal-burning plants are also big energy wasters. About 34% of the energy in coal burned in a typical electric power plant is used to produced electricity, and the remaining 66% ends up as waste heat that flows into the environment. As a result, U.S. coal-burning power plants throw away as much heat as all the energy used by Japan, the world's second largest economy.

15-2 WAYS TO IMPROVE ENERGY EFFICIENCY

How Can We Use Waste Heat? Could we save energy by recycling energy? No. The second law of energy tells us that we cannot recycle energy. However, we can slow the rate at which waste heat flows into the environment when high-quality energy is degraded.

For a house, the best way to do this is to **(1)** insulate it thoroughly, **(2)** eliminate air leaks (Figure 15-6),



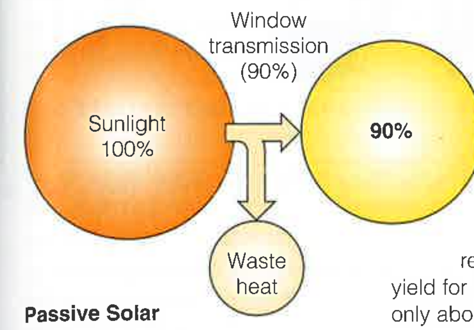


Figure 15-5 Comparison of net energy efficiency for two types of space heating. The cumulative net efficiency is obtained by multiplying the percentage shown inside the circle for each step by the energy efficiency for that step (shown in parentheses). Because of the second law of thermodynamics, in most cases the greater the number of steps in an energy conversion process, the lower its net energy efficiency. About 86% of the energy used to provide space heating by electricity produced at a nuclear power plant is wasted. If the additional energy needed to deal with nuclear wastes and to retire highly radioactive nuclear plants after their useful life is included, then the net energy yield for a nuclear plant is only about 8% (or 92% waste). By contrast, with passive solar heating, only about 10% of incoming solar energy is wasted.

and **(3)** equip it with an air-to-air heat exchanger to prevent buildup of indoor air pollutants.

In office buildings and stores, waste heat from lights, computers, and other machines can be collected and distributed to reduce heating bills during cold weather. During hot weather, the collected heat can be vented outdoors to reduce cooling bills.

How Can We Save Energy in Industry? Three important ways to save energy and money in industry are:

- **Cogeneration**, or *combined heat and power (CHP)* systems, in which two useful forms of energy (such as steam and electricity) are produced from the same fuel source. These systems have an efficiency of up to 80%

Figure 15-6 An infrared photo (thermogram) showing heat loss (red, white, and orange) around the windows, doors, roofs, and foundations of houses and stores in Plymouth, Michigan. Many homes and buildings in the United States (and in most other countries) are so full of leaks that their heat loss in cold weather and heat gain in hot weather are equivalent to having a large window-size hole in the wall of the house. (VANSCAN® Continuous Mobile Thermogram by Daedalus Enterprises, Inc.)

(compared to about 30–40% for coal-fired boilers and nuclear power plants) and emit two-thirds less carbon dioxide per unit of energy produced than conventional coal-fired boilers. Cogeneration has been widely used in western Europe for years, and its use in the United States and China is growing. In Germany, small cogeneration units that run on natural gas or liquefied petroleum gas (LPG) supply restaurants, apartment buildings, and houses with all their energy. In 6–8 years, they pay for themselves in saved fuel and electricity.

- *Replacing energy-wasting electric motors.* Running electric motors (mostly in industry) consumes about half of all electricity produced in the United States. Most of these motors are inefficient because they run only at full speed with their output throttled to match the task. Each year a heavily used electric motor consumes 10 times its purchase cost in electricity—equivalent to using $200,000 worth of gasoline each year to fuel a $20,000 car. The costs of replacing such motors with new adjustable-speed drive motors would be paid back in about 1 year and save an amount of energy equal to that generated by 150 large (1,000-megawatt) power plants.
- *Switching to high-efficiency lighting* (Guest Essay, p. 361).

How Can We Save Energy in Transportation? According to most energy analysts, the best way to save energy (especially oil) and money in transportation is to *increase the fuel efficiency of motor vehicles.*

Between 1973 and 1985, the average fuel efficiency doubled for new American cars and rose 37% for all passenger cars on the road because of government-mandated standards, called the Corporate Average Fuel Economy (CAFE) standards. CAFE regulations require new cars to meet certain average fuel efficiency standards, averaged over all cars produced.

Actually, between 1985 and 1999 the average fuel efficiency of new vehicles in the United States fell from 11 kilometers per liter (25.9 miles per gallon) to 10 kilometers per liter (23.8 miles per gallon) because of the popularity of **(1)** sport utility vehicles (SUVs), minivans, and light trucks (subject to much lower mileage standards than cars) and **(2)** larger, less efficient autos. According to the EPA, increasing average fuel economy by 1.3 hpl (3 mpg) would **(1)** save $25 billion a year in fuel costs, **(2)** reduce CO_2 emissions, and **(3)** save 1 million barrels of oil per day. However, automakers have successfully opposed any increase in the CAFE standards and are lobbying Congress to eliminate them.

Since 1985, at least 10 automobile companies have developed prototype cars with fuel efficiencies of 30–60 kilometers per liter (70–140 miles per gallon). These cars are **(1)** manufactured with light and strong materials, **(2)** meet current safety and air pollution standards,

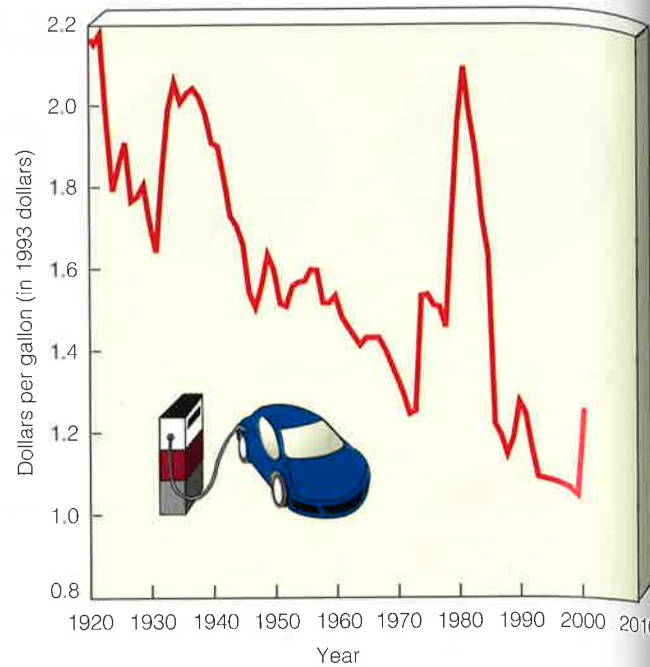


Figure 15-7 Real price of gasoline (in 1993 dollars) in the United States, 1920-2000. The 212 million motor vehicles in the United States use about 40% of the world's gasoline. Gasoline is one of the cheapest items American consumers buy. (U.S. Department of Energy)

carry four or five passengers, and **(3)** accelerate as rapidly as most current models.

If such cars were mass-produced, their slightly higher costs would be more than offset by their fuel savings. The problem is that there is little consumer interest in fuel-efficient cars mostly because **(1)** the inflation-adjusted price of gasoline today in the United States is low despite increases in gasoline prices in 2000 (Figure 15-7), and **(2)** two-thirds of consumers prefer SUVs and other large, inefficient vehicles.

Another way to save energy is to *shift to more energy-efficient ways to move people* (Figure 15-8) *and*

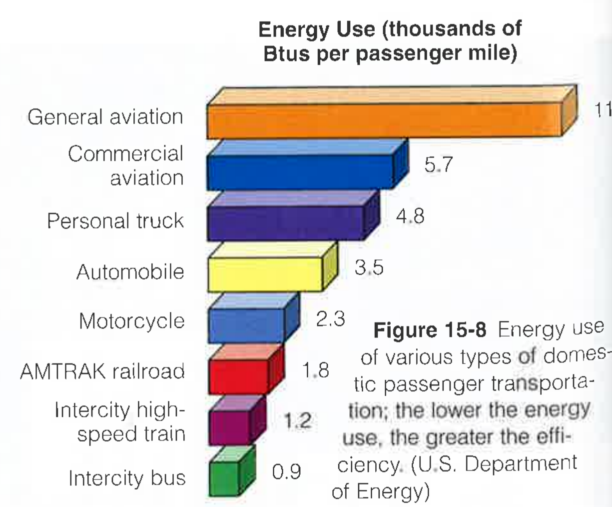


Figure 15-8 Energy use of various types of domestic passenger transportation; the lower the energy use, the greater the efficiency. (U.S. Department of Energy)

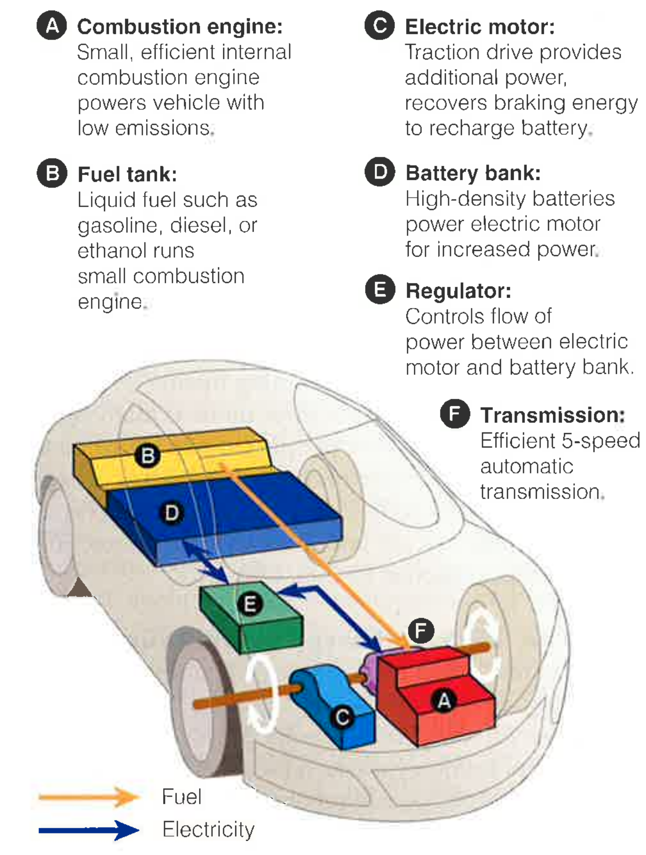


Figure 15-9 General features of a car powered by a *hybrid gas-electric engine.* A small internal combustion engine recharges the batteries, thus reducing the need for heavy banks of batteries and solving the problem of the limited range of conventional electric cars. The bodies of future models of such cars probably will be made of lightweight composite plastics that **(1)** offer more protection in crashes, **(2)** do not need to be painted, **(3)** do not rust, **(4)** can be recycled, and **(5)** have fewer parts than conventional cars. (Concept information from DaimlerChrysler, Ford, Honda, and Toyota)

freight. More freight could be shifted from trucks and planes to more energy-efficient trains and ships. New freight transport trucks could be made 50% more fuel-efficient than today's conventional trucks through use of improved aerodynamic design, turbocharged diesel engines, and radial tires.

Are Electric Cars the Answer? Conventional battery-powered *electric cars* are extremely quiet, need little maintenance, and can accelerate rapidly. The cars themselves produce no air pollution, but using coal and nuclear power plants to produce the electricity needed to recharge their batteries produces air pollution and nuclear wastes—something called *elsewhere pollution.* If solar cells or wind turbines could be used to recharge the car batteries, CO_2 and other air pollution emissions would be almost eliminated.

On the negative side, today's electric cars **(1)** can travel only 81–161 kilometers (50–100 miles) before needing a 3- to 8-hour recharge (although a new device may reduce recharge time to 10–20 minutes), and **(2)** batteries must be replaced about every 48,000 kilometers (30,000 miles) at a cost of at least $2,000. This plus the costs for daily recharging and a buying a recharger ($700–3,500) means that today's electric cars have twice the operating cost of gasoline-powered cars. Because of high costs and a lack of consumer interest, in 1999 major car companies abandoned their production of electric cars.

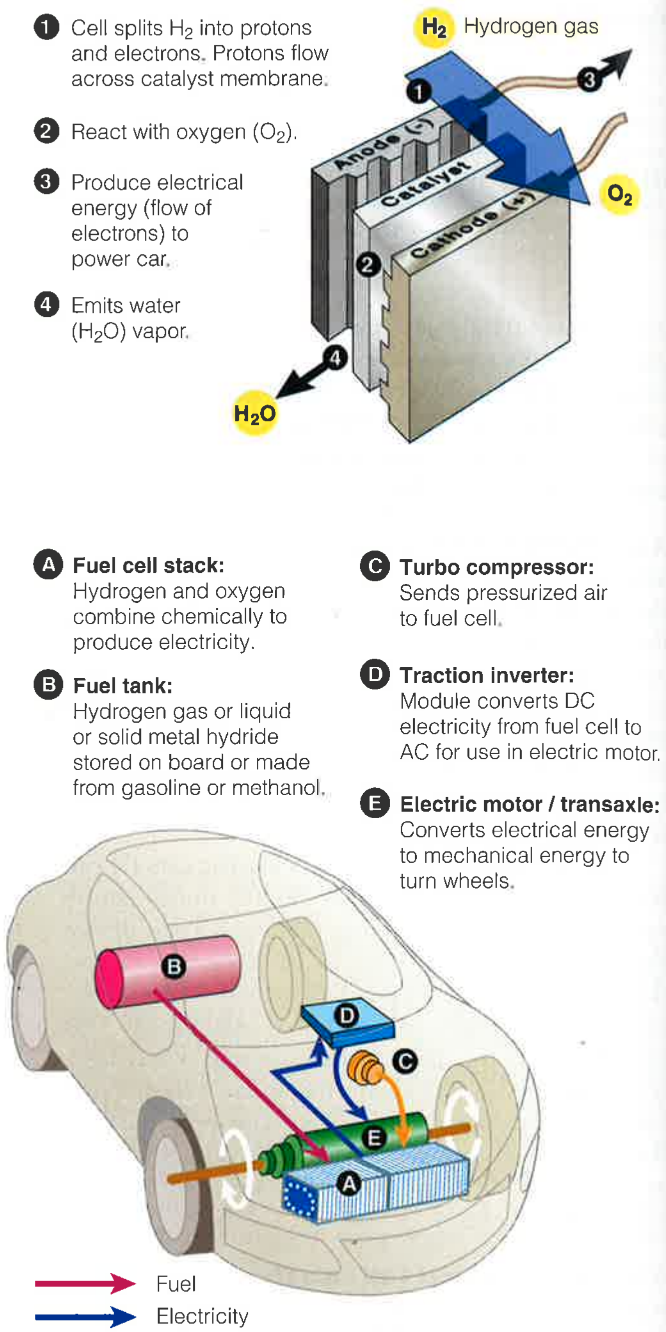
Are Hybrid and Fuel Cell Cars the Answer? There is growing interest in developing *superefficient cars* that could eventually get 34–128 kilometers per liter (80–300 miles per gallon). One type of highly efficient car uses **(1)** a small *hybrid electric-internal combustion engine* that runs on gasoline or some other liquid fuel and **(2)** a small battery (recharged by the internal combustion engine) to provide the energy needed for acceleration and hill climbing (Figure 15-9). In 1999, Toyota and Honda began selling the first generation of fuel-efficient hybrid engine cars.

Another type of superefficient car is an electric vehicle that uses *fuel cells* (Figure 15-10). Fuel cells consist of two electrodes immersed in a solution (electrolyte) that conducts electricity. They produce electricity by combining hydrogen and oxygen ions, typically from hydrogen and oxygen gas supplied as fuel for the cell (Figure 15-10). Such cars are 50–60% efficient (compared to 10–14% efficiency for gasoline-powered vehicles). As a result, fuel cell cars running on hydrogen should get 37–47 kilometers per liter (87–108 miles per gallon).

Most major automobile companies have developed prototype fuel-cell cars and hope to begin marketing them by 2004 using two different approaches. Some will be fueled by methanol (CH_3OH), a liquid usually produced from natural gas. A *liquid reformer system* in the engine extracts the hydrogen from methanol for use in the fuel cell. Drivers would fill up with methanol at pumps in conventional filing stations. A new process developed in 2000 allows fuel cells to produce hydrogen directly from hydrocarbons such as natural gas, gasoline, or diesel fuel. Instead of using complicated liquid fuel reformers, General Motors and Honda use a chemical process to store hydrogen fuel as a *solid metal hydride* compound that can be heated as needed to provide H_2.

How Can Electric Bicycles Reduce Energy Use and Waste? For urban trips, some people may begin using *electric bicycles,* now being sold by several companies such as EV Global Motors (founded by former Chrysler Corporation head Lee Iacocca). These bicycles are powered by a small electric motor and cost about $1,100. They **(1)** travel at up to 30 kilometers per hour (18 miles per hour), **(2)** go about 48 kilometers (30 miles) without pedaling on a full electric charge, and **(3)** produce

Figure 15-10 General features of an electric car powered by a *fuel cell* running on hydrogen gas. Such cars **(1)** will be almost pollution-free, emitting only water vapor and small amounts of nitrogen oxides and no CO_2, and **(2)** should get at least twice the mileage of comparable gasoline-powered cars. Several automobile companies have developed prototypes and are working to get costs down and improve hydrogen fuel storage systems. Early models could be on the road by 2004. (Concept information from DaimlerChrysler, Ford, Ballard, Toyota, and Honda)



no pollution during operation (and only a small amount for the electricity used in recharging them).

Globally there are about three times as many bicycles as cars because most people cannot afford cars. Increased use of electric bicycles and electric motor scooters in middle-income developing countries could reduce gasoline use, air pollution, CO_2 emissions, and urban gridlock (Section 25-3, p. 670).

How Can We Save Energy in Buildings? Most energy in residential and commercial buildings is used for heating, air conditioning, and lighting. The 110-story, twin-towered World Trade Center in New York City is a monument to energy waste: It uses as much electricity as a city of 100,000 people for about 53,000 employees.

In contrast, Atlanta's 13-story Georgia Power Company building uses 60% less energy than conventional office buildings of the same size. The largest surface of the building faces south to capture solar energy. Each floor extends out over the one below it, blocking out the higher summer sun to reduce air conditioning costs but allowing warming by the lower winter sun. Energy-efficient lights focus on desks rather than illuminating entire rooms. The Georgia Power model and other existing cost-effective commercial building technologies could **(1)** reduce energy use by 75% in buildings, **(2)** cut carbon dioxide emissions in half, and **(3)** in the United States save more than $130 billion per year in energy bills.

There are a number of ways to improve the energy efficiency of buildings, some of them discussed in the opening of this chapter (p. 358). One is to build more *superinsulated houses* (Figure 15-11). Such houses typically cost 5% more to build than conventional houses of the same size. However, this extra cost is paid back by energy savings within about 5 years and can save a homeowner $50,000–100,000 over a 40-year period.

Since the mid-1980s there has been growing interest in building superinsulated houses called *strawbale houses** with walls consisting of compacted bales of certain types of straw (available at a low cost almost everywhere) covered with plaster or adobe (Figure 15-12). By 2000, there were more than 1,200 such homes built or under construction in the United States (Guest Essay, p. 377). Using straw, an *annually* renewable agricultural residue often burned as a waste product, for the walls reduces the need for wood and thus slows deforestation. The main problem is getting banks and other moneylenders to recognize the potential of this and other unconventional types of housing and provide homeowners with construction loans.

Another way to save energy is to *use the most energy-efficient ways to heat houses* (Figure 15-13). The most energy-efficient ways to heat space are **(1)** a superinsulated house, **(2)** passive solar heating, **(3)** heat pumps in warm climates (but not in cold climates because at low temperatures they automatically switch to costly electric resistance heating), and **(4)** a high-efficiency (85–98%) natural gas furnace. The most wasteful and expensive way is to use electric resistance heating with the electricity produced by a coal-fired or nuclear power plant.

The energy efficiency of existing houses and buildings can be improved significantly by adding insulation, plugging leaks, and installing energy-saving windows and lighting. About one-third of heated air in U.S. homes and buildings escapes through closed windows and holes and cracks (Figure 15-6)—equal to the energy in all the oil flowing through the Alaska pipeline every year. During hot weather these windows and cracks also let heat in, increasing the use of air conditioning.

Replacing all windows in the United States with low-E (low-emissivity) windows would cut these expensive losses by two-thirds and reduce CO_2 emissions. Widely available superinsulating windows insulate as well as 8–12 sheets of glass. Although they cost 10–15% more than double-glazed windows. this cost is paid back rapidly by the energy they save. Even better windows will reach the market soon.

Simply wrapping a water heater in a $20 insulating jacket can save a homeowner $45 a year and reduce CO_2 emissions. Leaky ducts allow 20–30% of a home's heating and cooling energy to escape and draw unwanted moisture and heat into the home. Careful sealing can reduce this loss. Some designs for new homes keep the ducts inside the home's thermal envelope so that escaping hot or cool air leaks into the living space.

An energy-efficient way to heat hot water for washing and bathing is to use tankless instant water heaters (about the size of bookcase loudspeakers) fired by natural gas or LPG. These devices, widely used in many parts of Europe, heat the water instantly as it flows through a small burner chamber and provide hot water only when it is needed. A well-insulated, conventional natural gas or LPG water heater is fairly efficient. However, all conventional natural gas and electric resistance heaters waste energy by keeping a large tank of water hot

*Strawbale houses and barns were first built in Nebraska the early 1900s because no trees were available. Some of these durable structures are still in use today. For information on strawbale houses, see Steen et al., *The Straw Bale House* (White River Junction, Vt.: Chelsea Green, 1994); and GreenFire Institute, 1509 Queen Anne Ave. North, #606, Seattle, WA 98109, 206-284-7470.

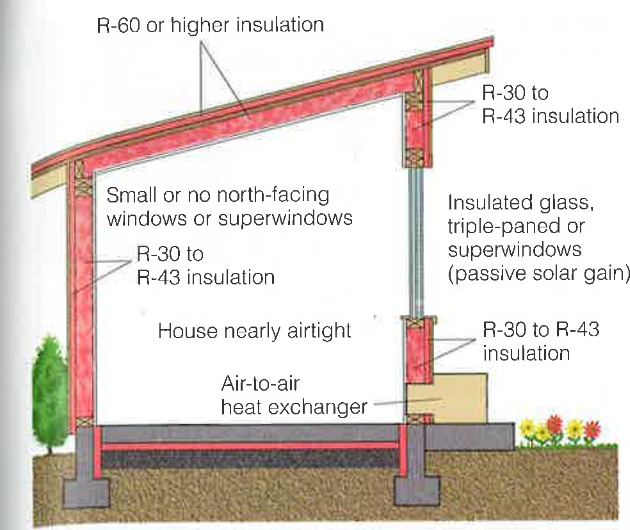


Figure 15-11 Major features of a superinsulated house. Such a house is so heavily insulated and so airtight that it can be warmed by heat from direct sunlight, appliances, and human bodies, with little or no need for a backup heating system. An air-to-air heat exchanger prevents buildup of indoor air pollution.

Figure 15-12 An energy-efficient, environmentally healthy, and affordable Victorian-style strawbale house designed and built by Alison Gannett in Crested Butte, Colorado. The left photo is during construction, and the right photo is the completed house. Depending on the thickness of the bales, plastered strawbale walls have an insulating value of R-35 to R-60, compared to R-12 to R-19 in a conventional house. (The R-value is a measure of resistance to heat flow.) (Alison Gannett)

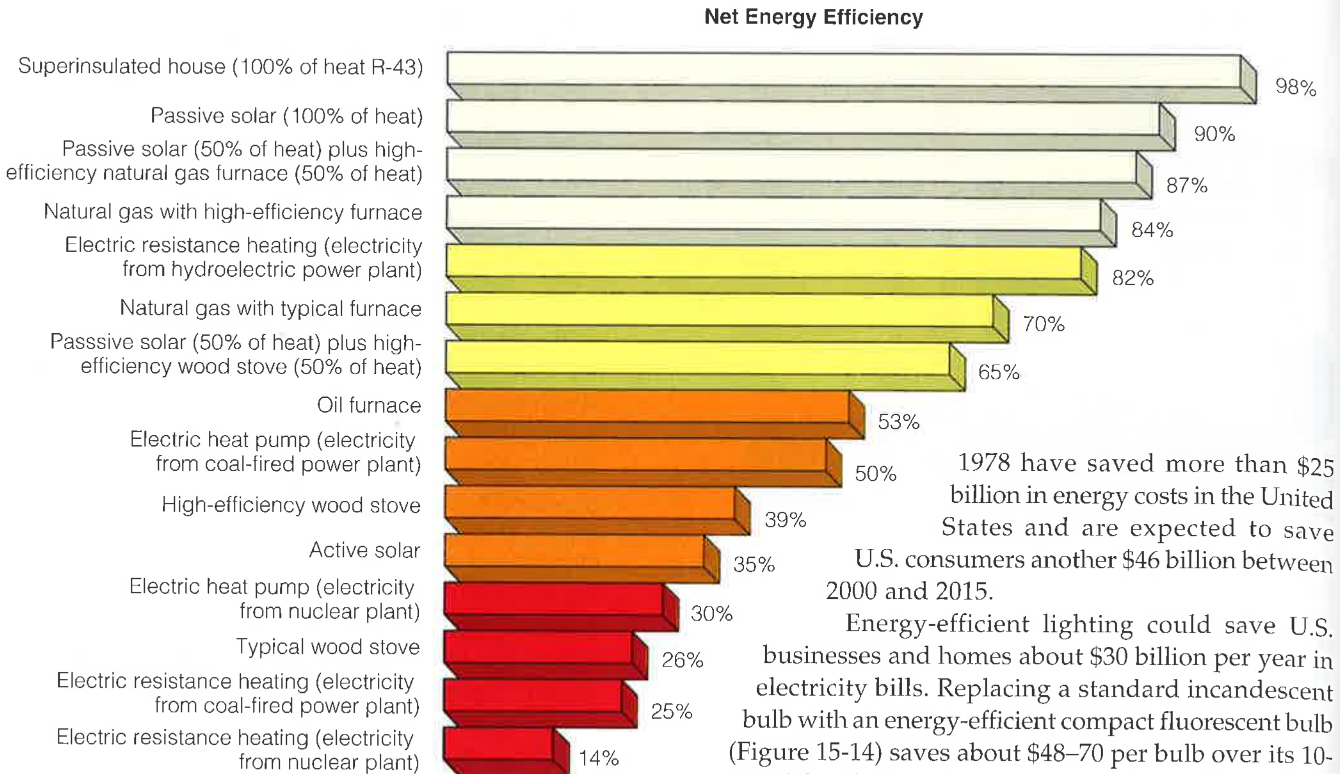


Figure 15-13 Net energy efficiencies for various ways to heat an enclosed space such as a house. (Data from Howard T. Odum)

all day and night and can run out after a long shower or two.

Using electricity produced by any type of power plant is the most inefficient and expensive way to heat water for washing and bathing. A $425 electric water heater can cost $5,900 in energy over its 15-year life, compared to about $4,000 for a comparable natural gas water heater over the same period.

Setting higher energy-efficiency standards for new buildings would also save energy. Building codes could require that all new houses use 60–80% less energy than conventional houses of the same size, as has been done in Davis, California (p. 658). Because of tough energy-efficiency standards, the average Swedish home consumes about one-third as much energy as the average American home of the same size.

Another way to save energy is to *buy the most energy-efficient appliances and lights.** Federal energy efficiency standards set for more than 20 appliances—including a tripling of refrigerator efficiency—since 1978 have saved more than $25 billion in energy costs in the United States and are expected to save U.S. consumers another $46 billion between 2000 and 2015.

Energy-efficient lighting could save U.S. businesses and homes about $30 billion per year in electricity bills. Replacing a standard incandescent bulb with an energy-efficient compact fluorescent bulb (Figure 15-14) saves about $48–70 per bulb over its 10-year life. Thus, replacing 25 incandescent bulbs in a house or building with energy-efficient fluorescent bulbs saves $1,250–1,750. Students in Brown University's environmental studies program showed that the school could save more than $40,000 per year just by replacing the incandescent light bulbs in exit signs with compact fluorescent bulbs.

According to the Alliance to Save Energy, if every U.S. household replaced four 100-watt incandescent light bulbs that burn 4 hours or more per day with 23-watt fluorescent bulbs, the reduced air pollution would equal that from 7 million cars. Despite their advantages, less than 10% of U.S. homes use these energy- and money-saving bulbs, which pay for themselves in 2–4 years. Studies show that such low use has resulted from **(1)** the high initial cost of the bulbs, **(2)** lack of information and education about life-cycle costing, **(3)** initial lack of suitable light fixtures for these larger bulbs (light fixtures and smaller bulbs are now available), and **(4)** dissatisfaction with the color and intensity of the light produced compared to incandescent bulbs (corrected with newer bulbs).

The energy saved from this fairly small use of fluorescent bulbs has largely been wiped out by sales of cheap halogen torchière lamps. Halogen bulbs are **(1)** very inefficient, **(2)** emit large amounts of heat that increase air-conditioning bills, and **(3)** have caused fires. More efficient and safer incandescent versions of the lamps are now available.

If all U.S. households used the most efficient frost-free refrigerator now available, 18 large (1,000-megawatt) power plants could close. Microwave ovens can cut electricity use for cooking by 25–50% (but not if used for defrosting food). Clothes dryers with moisture sensors cut energy use by 15%, and front-loading washers use 50% less energy than top-loading models but cost about the same. New microwave clothes dryers soon to be available will use 15% less energy than conventional electric dryers and 28% less energy than gas units. Increased use of the internet for business and shopping transactions reduces energy use and decreases emissions of carbon dioxide and other air pollutants (Connections, above).

*Each year the American Council for an Energy-Efficient Economy (ACEEE) publishes a list of the most energy-efficient major appliances mass-produced for the U.S. market. A copy can be obtained from the council at 1001 Connecticut Ave. NW, Suite 801, Washington, DC 20036. Each year they also publish *A Consumer Guide to Home Energy Savings*, available in bookstores or from the ACEEE.

CONNECTIONS: Using the Internet to Save Energy and Paper and Reduce Global Warming

According to a study by Forrester Research, between 1998 and 2003, **(1)** consumer e-commerce is expected to grow from $7.8 billion to $108 billion, and **(2)** business e-commerce is expected to rise from $43 billion to $1 trillion.

In addition to revolutionizing business practices around the world, the internet is having a positive environmental impact. According to a 2000 report by researchers at the Center for Energy and Climate Solutions, increasing use of the internet is saving energy by:

- Allowing more employees to work at home and allowing highly mobile workers to be assigned flexible office space only when they are in the office.
- Saving energy and material resources by allowing a reduction in retail, manufacturing, warehouse, and commercial office space. Some online companies keep no merchandise in warehouses and have it shipped to customers directly from manufacturers. Many manufacturers are using the internet to sell their goods directly to consumers and other businesses. For example, Home Depot uses information technology and the internet to move 85% of its merchandise directly from manufacturers to their stores.
- Using less energy to get products from sellers to consumers. Sending a package by overnight air uses about 40% less fuel than driving round-trip to the mall to get the product. Shipping by rail saves even more energy.
- Not being a major energy user because the internet draws heavily on the existing communication infrastructure. The average personal computer and monitor use only 150 watts of power, and this is dropping because of increased use of more energy-efficient models and laptops.
- Reducing the energy, paper, and materials used to produce, package, and market consumer items such as computer software and music CDs by allowing them to be downloaded.
- Reducing energy used in transporting goods by using internet-based systems to auction off empty shipping space on trucks, aircraft, and trains.

The resulting savings in energy consumption also reduce air pollution and carbon dioxide emissions by reducing fossil fuel use. By 2010, the projected energy savings from increased business on the internet should reduce carbon dioxide emissions by an amount equivalent to that from 170 large (1,000,000-kilowatt) coal-burning power plants.

Paper production (a highly energy- and resource-intensive industry) is expected to decrease as **(1)** consumers use the internet to download software and view magazines, newspapers, research articles, telephone directories, encyclopedias, and books, **(2)** consumers and businesses send more e-mail and less mail and reports by envelope and packages, and **(3)** easily updated online catalogs replace paper catalogs.

Critical Thinking

What types of environmental harm might be increased by greatly expanded use of the internet to sell more and more goods in the global marketplace?

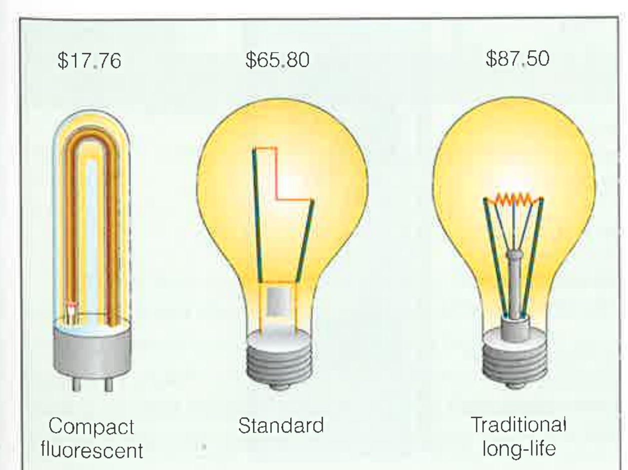


Figure 15-14 Cost of electricity for comparable light bulbs used for 10,000 hours. Because conventional incandescent bulbs are only 5% efficient and last only 1,500 hours, they waste enormous amounts of energy and money and add to the heat load of houses during hot weather. Socket-type fluorescent lights use one-fourth as much electricity as conventional bulbs. Although these bulbs cost $6–15 per bulb, they last up to 100,000 hours (60–70 times longer than conventional incandescent bulbs and 25 times longer than halogen bulbs), saving a lot of money (compared with less efficient incandescent and halogen bulbs) over their long life. Recently, smaller compact fluorescent bulbs (costing about $6) that fit into ordinary light fixtures and ones that can be dimmed have been developed. (Data from Electric Power Research Institute)

Why Aren't We Doing More to Reduce Energy Waste? With such an impressive array of benefits (Figure 15-3), why isn't there more emphasis on improving energy efficiency? The major reasons are as follows:

- A glut of low-cost fossil fuels (Figure 14-18, p. 339, and Figure 15-7). As long as energy is cheap, people are more likely to waste it and not make investments in improving energy efficiency.
- Lack of sufficient tax breaks and other economic incentives for consumers and businesses to invest in improving energy efficiency.
- Lack of information about the availability of energy-saving devices and the amount of money such items can save consumers by using *life cycle cost* analysis.

15-3 USING SOLAR ENERGY TO PROVIDE HEAT AND ELECTRICITY

What Are the Major Advantages and Disadvantages of Solar Energy? In 1999, renewable energy provided about 9% of the commercial energy used in the United States (Figure 14-13, p. 333). About 4% of this energy came from hydropower, 3% from biomass and geothermal, and 2% from wind and direct solar energy. California—with the world's sixth largest economy—gets 12% of its electricity from renewable wind, geothermal, solar, and biomass sources.

This could change over the next 20–50 years. In 1994, Shell International Petroleum in London projected that renewable energy (especially using wind and solar cells to produce electricity and to produce hydrogen for fuel cells) could account for 50% of world energy production by 2050.

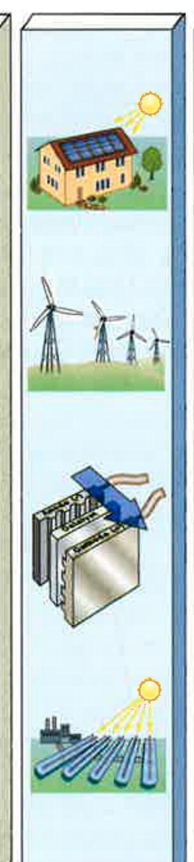
Figure 15-15 lists some of the advantages and disadvantages of making a shift to greatly increased use of direct solar energy and indirect forms of solar energy such as wind. Like fossil fuels and nuclear power (Chapter 14), each renewable energy alternative has a mix of advantages and disadvantages, as discussed in the remainder of this chapter.

How Can We Use Solar Energy to Heat Houses and Water? Buildings and water can be heated by solar energy using two methods: passive and active (Figure 15-16). A **passive solar heating system** absorbs and stores heat from the sun directly within a structure (Figures 15-1, 15-16 (left), and 15-17 and Guest Essay, p. 377). Energy-efficient windows, greenhouses, and sunspaces face the sun to collect solar energy by direct gain. Walls and floors of concrete, adobe, brick, stone, salt-treated timber, and water in 55-gallon drums store much of the collected solar energy as heat and release it slowly throughout the day and night. A small backup heating system such as a vented natural gas or propane heater may be used but is not necessary in many climates.

Engineer and builder Michael Sykes has designed and built several versions of a solar envelope house that is heated and cooled passively by solar energy, with the energy stored and slowly released by massive timbers and the earth beneath the house (Figure 15-18). The front and back of this house are double walls of heavy timber impregnated with salt to increase the wood's ability to store heat. The space between the two walls and the basement forms a convection loop or envelope around the inner shell of the house. In summer, roof vents release heated air from the convection loop throughout the day; at night, these roof vents, with the aid of a fan, draw air into the loop, passively cooling the house. The interior temperature of the house typically stays within 2° of 21°C (70°F) year-round without any conventional cooling or heating system. In cold or cloudy climates, a small wood stove or vented natural gas heater in the basement can be used as a backup to heat the air in the convection loop.

Advantages

- Save money (wind)
- Reduce air pollution (99% less than coal)
- Greatly reduce CO_2 emissions
- Reduce dependence on imported oil
- Last as long as coal and nuclear plants (30–40 years)
- Land use less than for coal
- Low land use with new solar cell and window glass system
- Backup and storage devices available (such as gas turbines, batteries, and flywheels)
- Backup need reduced by distributing and storing solar-produced hydrogen gas



Disadvantages

- Making solar cells produces toxic chemicals
- Solar systems last only 30–40 years
- Take large amounts of land because of diffuse nature of sunlight
- Can damage fragile desert ecosystems used to collect solar energy
- Need backup systems at night and during cloudy and rainy weather

Figure 15-15 Major advantages and disadvantages of using direct and indirect solar energy systems to produce heat and electricity. Specific advantages and disadvantages of different direct and indirect solar and other renewable energy systems are discussed in this chapter.

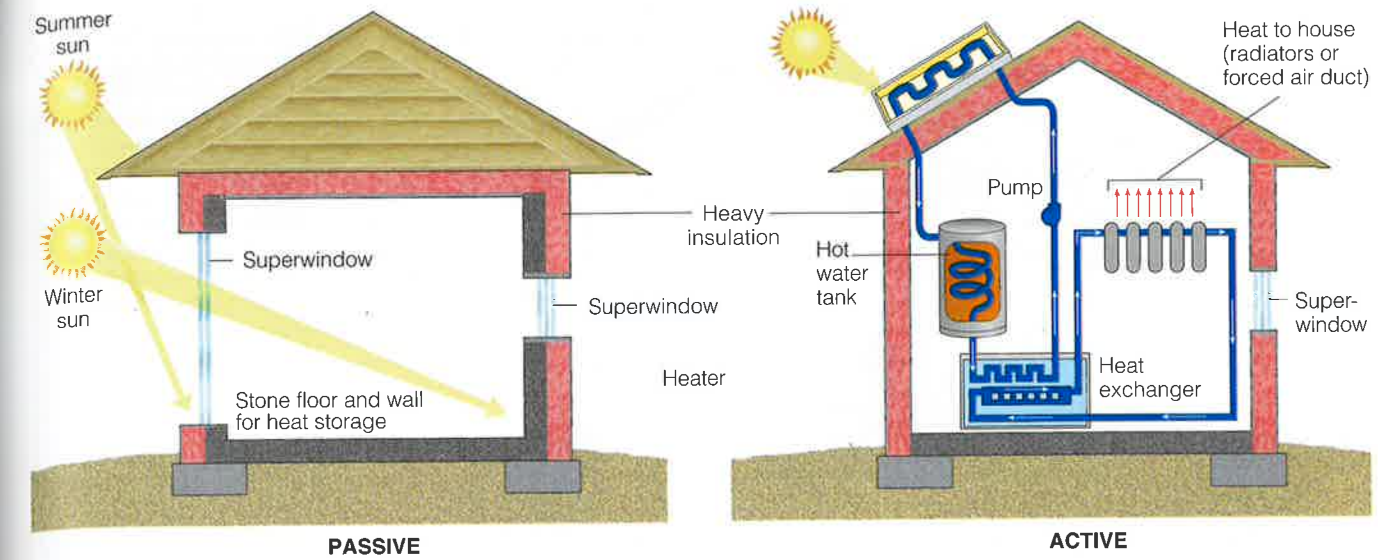


Figure 15-16 Passive and active solar heating for a home.

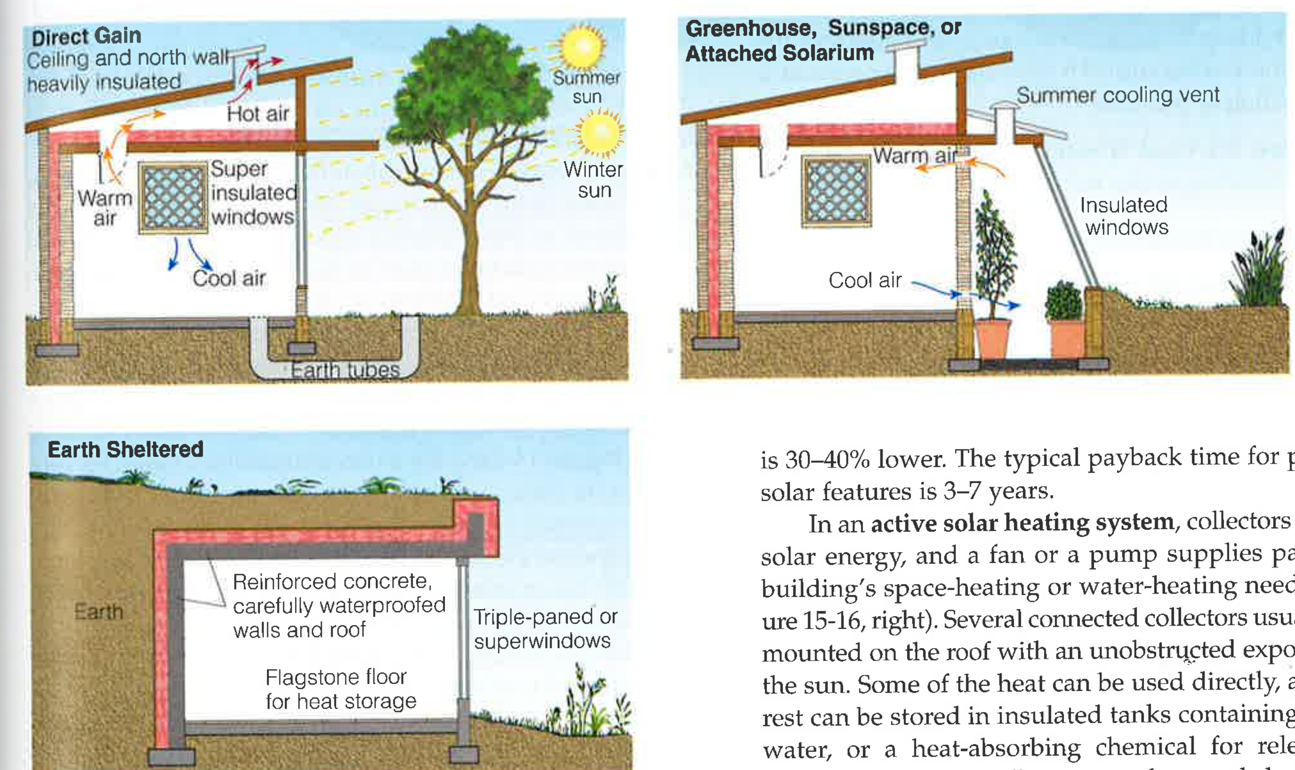


Figure 15-17 Three examples of passive solar design for houses.

On a life cycle cost basis, good passive solar and superinsulated design is the cheapest way to heat a home or small building in regions where ample sunlight is available during daylight hours (Figure 15-19). Such a system usually adds 5–10% to the construction cost, but the life cycle cost of operating such a house is 30–40% lower. The typical payback time for passive solar features is 3–7 years.

In an **active solar heating system**, collectors absorb solar energy, and a fan or a pump supplies part of a building's space-heating or water-heating needs (Figure 15-16, right). Several connected collectors usually are mounted on the roof with an unobstructed exposure to the sun. Some of the heat can be used directly, and the rest can be stored in insulated tanks containing rocks, water, or a heat-absorbing chemical for release as needed. Active solar collectors can also supply hot water.

Figure 15-20 lists the major advantages and disadvantages of using passive or active solar energy for heating buildings. As architects, developers, and home buyers become more aware of the monetary and aesthetic values of good passive solar design, its use in new homes should increase in areas with ample sunlight. However, passive solar cannot be used to heat existing homes and buildings **(1)** not oriented to receive sunlight and **(2)** whose access to sunlight is blocked by other buildings and structures. Most analysts do not

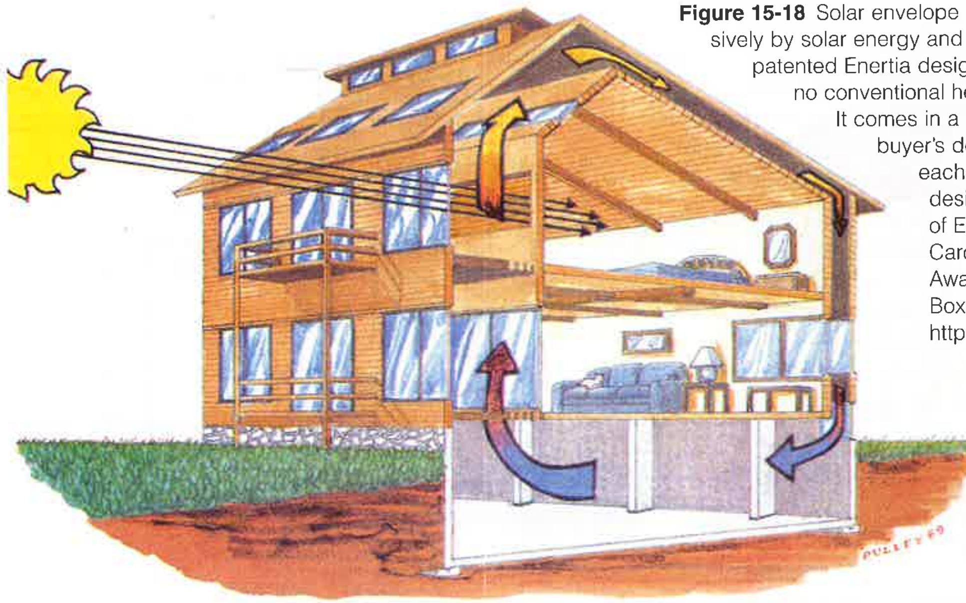


Figure 15-18 Solar envelope house that is heated and cooled passively by solar energy and the earth's thermal energy. This patented Enertia design developed by Michael Sykes needs no conventional heating or cooling system in most areas. It comes in a precut kit engineered and tailored to the buyer's design goals. Sykes plants 50 trees for each one used in his house kits, and his design has received both the Department of Energy's Innovation Award and the North Carolina Governor's Energy Achievement Award. (Enertia Building Systems, Rt. 1, Box 67, Wake Forest, NC 27587; Web site: http://www.enertia.com)

expect widespread use of active solar collectors for heating houses because of high costs, maintenance, and unappealing appearance.

How Can We Cool Houses Naturally? Ways to make a building cooler include:

- Using superinsulation and superinsulating windows.
- Blocking the high summer sun with deciduous trees, window overhangs, or awnings (Figure 15-17, top left).
- Using windows and fans to take advantage of breezes and keep air moving.
- Suspending reflective insulating foil in an attic to block heat from radiating down into the house.
- Placing plastic (PVC) *earth tubes* 3–6 meters (10–20 feet) underground where the earth is cool year-round and using a tiny fan to pipe cool and partially dehumidified air into an energy-efficient house (Figure 15-17 top left).*
- Using solar-powered evaporative air conditioners (which work well only in dry climates and cost too much for residential use).

How Can We Use Solar Energy to Generate High-Temperature Heat and Electricity? Several so-called *solar thermal systems* collect and transform radiant energy from the sun into high-temperature thermal energy (heat), which can be used directly or converted to electricity (Figure 15-21). In one such *central receiver system*, called a *power tower*, huge arrays of computer-controlled mirrors called *heliostats* track the sun and focus sunlight on a central heat collection tower (Figure 15-21a).

A government-subsidized power tower system, called Solar Two, began operating in the California desert in 1996. However, this experimental plant **(1)** cost about eight times more to build than a coal-fired plant, **(2)** produced electricity at about twice the cost of a coal-fired plant, and **(3)** was shut down in 1999.

In a *solar thermal plant* or *distributed receiver system*, sunlight is collected and focused on oil-filled pipes running through the middle of curved solar collectors (Figure 15-21b). This concentrated sunlight can generate temperatures high enough for industrial processes or for producing steam to run turbines and generate electricity. At night or on cloudy days, high-efficiency combined-cycle natural gas turbines can supply backup electricity as needed. In California's Mojave Desert, such a solar thermal system with a natural gas turbine backup system produced power much more cheaply than nuclear power plants. However, the company went bankrupt, partly because of a lack of tax breaks that were available for fossil fuel and nuclear power plants.

Another type of distributed receiver system uses *parabolic dish collectors* (that look somewhat like TV satellite dishes) instead of parabolic troughs. These collectors can track the sun along two axes and generally are more efficient than troughs. A pilot plant is being built in northern Australia. The U.S. Department of Energy projects that early in this century parabolic dishes with a natural gas turbine backup should be able to produce electrical power costing about the same as that from coal-burning plants.

*They work. I used them in a passively heated and cooled office and home for 15 years. People allergic to pollen and molds should add an air purification system, but this is also necessary with a conventional cooling system.

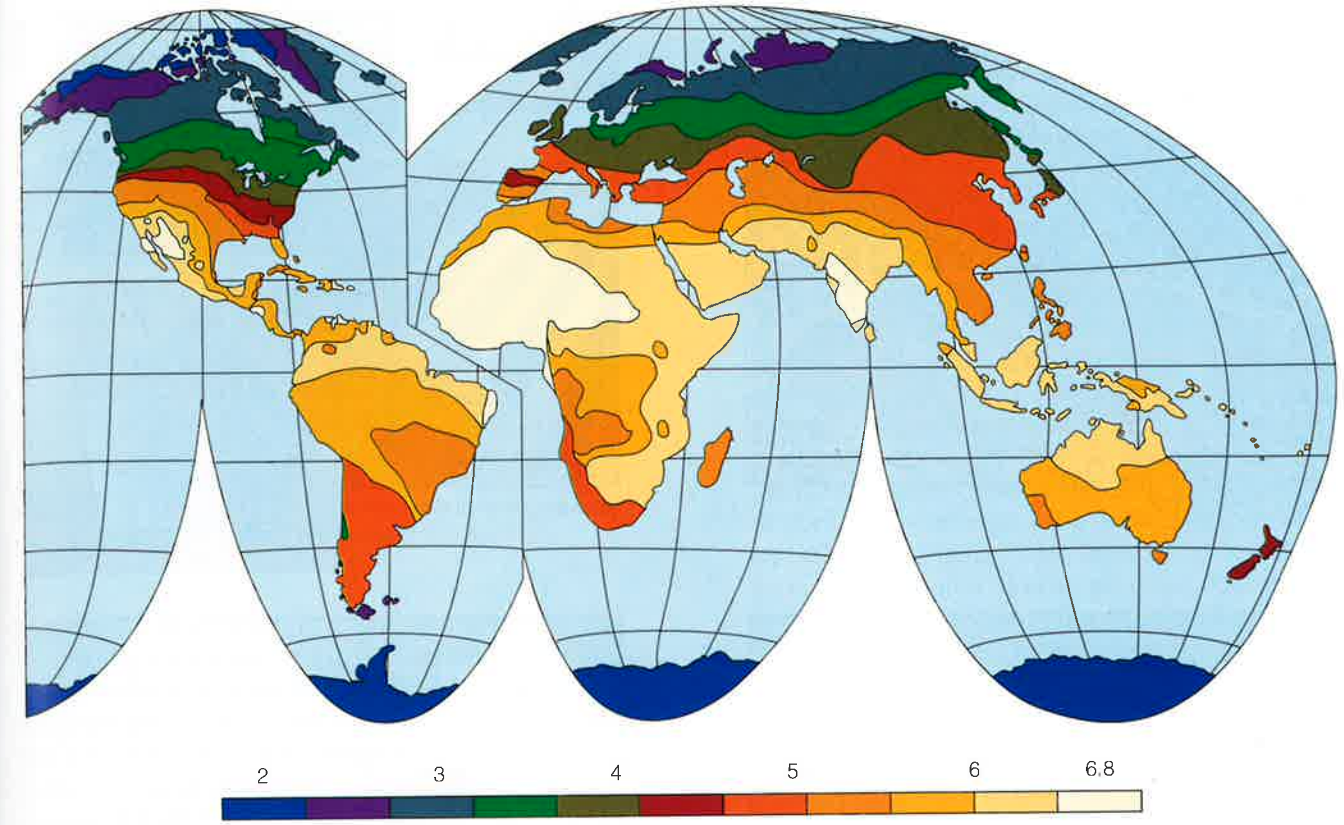


Figure 15-19 Map of global solar energy availability. Areas with more than 3.5 kilowatt-hours per square meter per day (see scale) are good candidates for passive and active solar heating systems and use of solar cells to produce electricity. (Data from U.S. Department of Energy)

Another approach for intensifying incoming solar energy about 80,000 times is a *nonimaging optical solar concentrator*. With this technology, the sun's rays are allowed to scramble instead of being focused on a particular point (Figure 15-21c). Because of its high efficiency and ability to generate extremely high temperatures, nonimaging concentrators may make solar energy practical for widespread industrial and commercial use within 10-20 years.

Inexpensive solar cookers can focus and concentrate sunlight and cook food, especially in rural villages in sunny developing countries. They can be made by fitting an insulated box big enough to hold three or four pots with a transparent, removable top (Figure 15-21d). Solar cookers reduce deforestation for fuelwood, the time and labor needed to collect firewood, and indoor air pollution from smoky fires.

Figure 15-22 lists the advantages and disadvantages of concentrating solar energy to produce high-temperature heat or electricity. Most analysts do not expect widespread use of such technologies over the next few decades because of their high costs and the availability of much cheaper ways to produce electricity such as combined-cycle natural gas turbines and wind turbines.

How Can We Produce Electricity with Solar Cells? Solar energy can be converted directly into electrical energy by **photovoltaic (PV) cells**, commonly

Advantages	Disadvantages
Energy is free	Need access to sun 60% of time
Net energy is moderate (active) to high (passive)	Blockage of sun access by other structures
Quick installation	Need heat storage system
No CO_2 emissions	High cost (active)
Very low air and water pollution	Active system needs maintenance and repair
Very low land disturbance (built into roof or window)	Active collectors unattractive
Moderate cost (passive)	

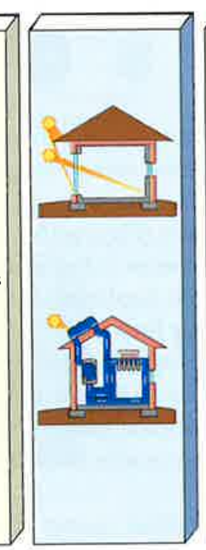


Figure 15-20 Advantages and disadvantages of heating a house with passive or active solar energy.

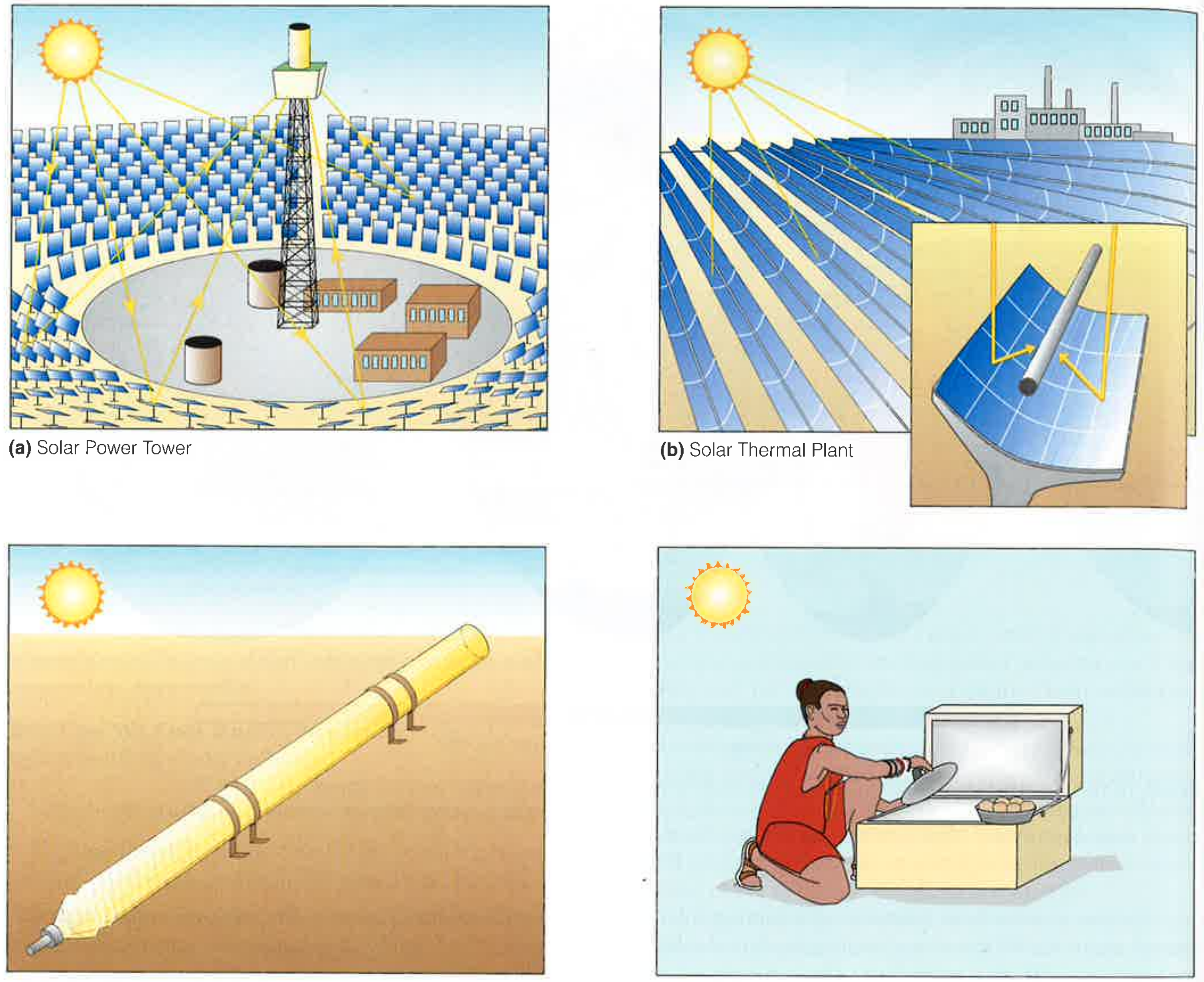


Figure 15-21 Several ways to collect and concentrate solar energy to produce high-temperature heat and electricity. Because of their high costs (except for solar ovens), such systems are not expected to provide much of the world's energy.

called **solar cells** (Figure 15-23). A solar cell is a transparent wafer that contains a *semiconductor* material with a thickness ranging from less than that of a human hair to a sheet of paper. Sunlight energizes and causes electrons in the semiconductor to flow, creating an electrical current.

Because a single solar cell produces only a tiny amount of electricity, many cells are wired together in modular panels to produce the amount of electricity needed. The direct current (DC) electricity produced can be **(1)** stored in batteries and used directly or **(2)** converted to conventional alternating-current (AC) electricity by a separate inverter or an inverter built into the cells (Guest Essay, p. 377).

Traditional-looking solar-cell roof shingles and photovoltaic panels that resemble metal roofs (developed in Japan) reduce the cost of solar-cell installations by saving on roof costs (Figure 15-23). With this technology, the roof becomes a building's power plant. Solar cells also can be deployed along highways, on bridges, over parking lots, on or under bridges, and atop municipal buildings. A German company is testing a *solar-electric window* that incorporates solar cells into a semitransparent glazing that simultaneously generates electricity and provides filtered light during daylight hours.

Researchers envision using easily expandable banks of solar cells to **(1)** provide electricity for rural vil-

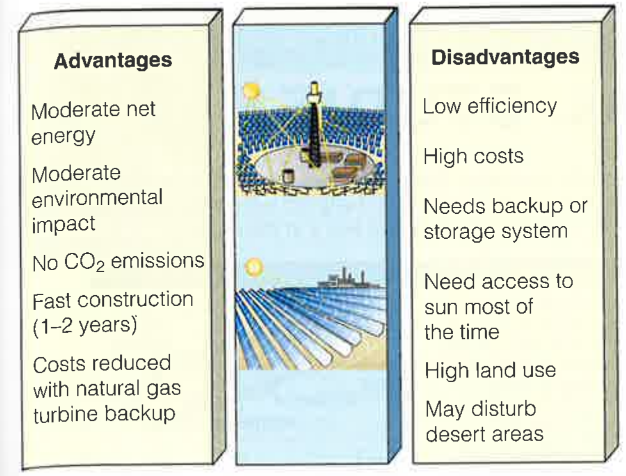


Figure 15-22 Advantages and disadvantages of using solar energy to generate high-temperature heat and electricity.

lages in developing countries, **(2)** produce electricity at a small power plant, using combined-cycle natural gas turbines to provide backup power when the sun is not shining, and **(3)** convert water to hydrogen gas that can be distributed to energy users by pipeline, as natural gas is. Researchers are developing flywheels, improved deep-cycle batteries, and supercapacitors to store solar (or wind) power for later use as needed. One promising system is to **(1)** use rooftop solar cells to produce hydrogen when the sun is shining, **(2)** store the hydrogen, and **(3)** use it in a fuel cell to provide electricity and heat as needed.

In New York City, the Durst Building at 4 Times Square incorporates green design on a grand scale. This 48-story skyscraper uses **(1)** low-E insulating windows, **(2)** energy-efficient lighting, **(3)** PV panels built into the walls along its south and east sides, **(4)** two large fuel cells in the basement that provide hot water, supplement daytime electricity, and provide all the building's electricity at night, **(5)** recycled building materials, and **(6)** separate waste chutes to facilitate recycling by tenants. This design is projected to produce 40% fewer greenhouse gas emissions than a traditionally powered building of the same volume.

In 1998, the 350-room Mauna Lani Bay Hotel, a luxury resort on the Kona-Kohala coast of the island of Hawaii, covered its roof with solar cells, which act as a 100-kilowatt power station.

Oberlin College in Ohio recently built a new environmental studies center incorporating major elements of *green design*, including use of passive solar energy and solar cells (Figure 15-24). David Orr (head of Oberlin's environmental studies program, Guest Essay, p. 683) designed the building with the help of more than 250 students, faculty, and townspeople.

In 1999, researchers announced the development of a new breed of solar cells that are thinner than a human hair and can be created with materials costing only a few pennies. Instead of silicon, they consist of an ultrathin layer of a semiconductor compound (copper indium diselenide) deposited on a material such as glass. Mass production and technological advances could bring costs down as low as 4¢ per kilowatt-hour by 2015—below the cost of all other ways to produce electricity. (A kilowatt-hour of electricity can light a 100-watt light bulb all night or run a typical hairdryer for about 1 hour.)

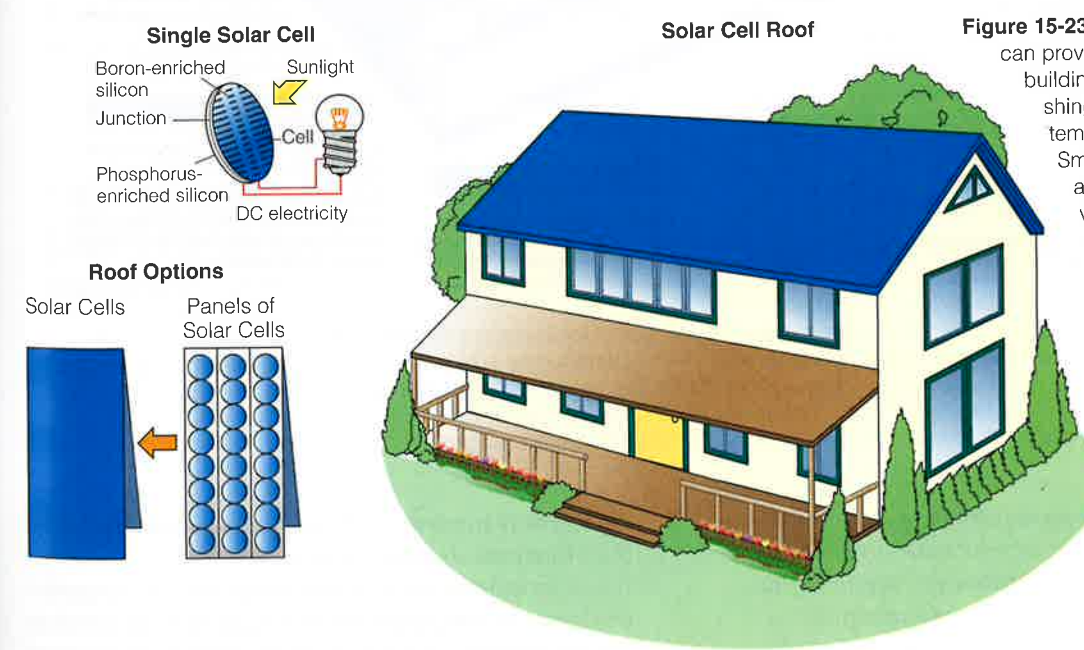


Figure 15-23 Photovoltaic (solar) cells can provide electricity for a house or building using new solar-cell roof shingles or PV panel roof systems that look like metal roofs. Small and easily expandable arrays of such cells can provide electricity for urban villages throughout the world without large power plants or power lines. Large banks of such cells can also produce electricity at a small power plant for direct use or for converting water to hydrogen fuel. As the price of such electricity drops, usage is expected to increase dramatically.

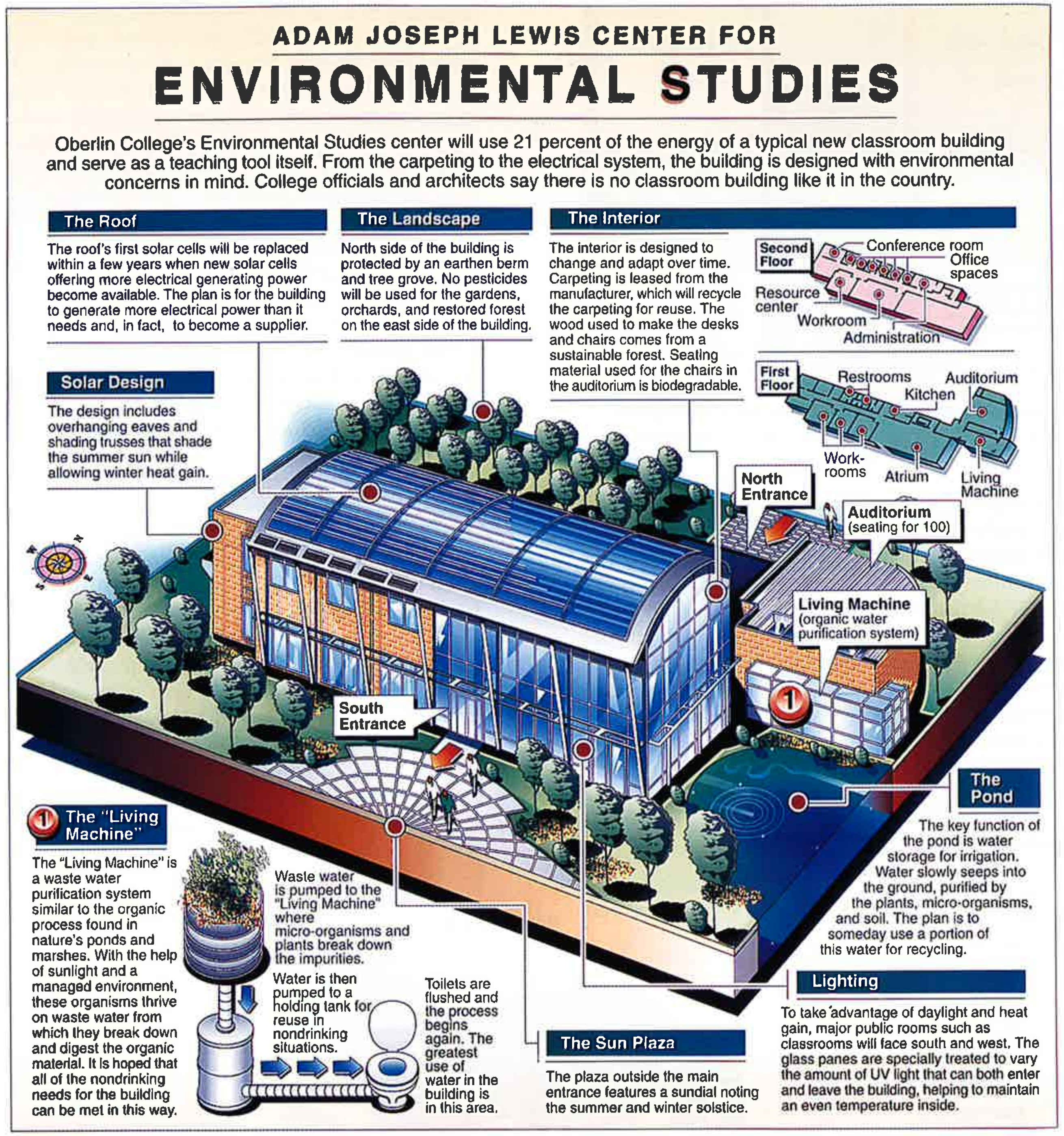


Figure 15-24 Major elements of green design in the Adam Joseph Lewis Center for Environmental Studies at Oberlin College in Ohio. There were no waste products as a result of the construction and no use of toxic materials. The building is the brainchild of David Orr (head of Oberlin's Environmental Studies program) and a number of students, faculty, and townspeople. In North Carolina, Catawba College's Center for the Environment is also a model of green design. (Illustration by James Owen. Courtesy of Oberlin College)

In 2000, researchers were working to produce electricity from solar cells made of microscopic quantum rods 1 nanometer (1 billionth of a meter) thick and 1–10 nanometers long. They contain tiny microscopic crystals, each consisting of clusters of 100–100,000 molecules of cadmium selenide, a semiconducting material. Researchers hope to produce these large quantities of quantum rods to make these solar cells.

Solar cells are an ideal technology for providing electricity to 2 billion people in rural areas in most developing countries who have no electricity. With financing from the World Bank, India (the world's number-one market for solar cells) is installing solar-cell systems in 38,000 villages, and Zimbabwe is bringing solar electricity to 2,500 villages. Houston-based Enron Corporation announced plans to build large, grid-connected solar photovoltaic power plants in the desert regions of China, India, and the United States. In 1999, Shell Oil (which owns two PV companies) launched a solar electrification project in South Africa that will provide 50,000 homes in impoverished areas with solar panels and batteries.

In 1998, the U.S. Department of Energy launched a program to encourage utilities, the solar industry, and governments to work together to install solar-cell

GUEST ESSAY

Living Lightly on the Earth at Round Mountain Organics

Nancy Wicks

Nancy Wicks is an ecopioneer trying to live her ideals. She grew up in a small town in Iowa and did undergraduate studies in a village in Nepal. Both of these life experiences inspired her to live more sustainably by creating Round Mountain Organics, an organic garden at an altitude of 1.6 kilometers (8,500 feet) in the Rocky Mountains near Crested Butte, Colorado. Nancy lives in a passive solar strawbale house, which is powered by the wind and sun. She's a fanatic reuser, recycler, and composter. She received the "Sustainable Business of the Year, 2000" award from the High Country Citizen's Alliance.

After studying in Nepal, where sustainability is a do or die situation, I have tried incorporate as many sustainable practices into my life as possible at my house and organic garden business called Round Mountain Organics. This includes **(1)** being a member of a buying co-op (where buying in bulk not only saves re-sources but also saves money), **(2)** reusing everything from plastic and paper bags to trays and pots for garden plants, and **(3)** composting food waste (which saves money on trash bills and fertilizes the soil).

After moving onto the land that is now home to Round Mountain Organics, I spent 4 years planning and building an octagonal strawbale house with a stucco exterior—the first such house to be built in the county. I chose to build with straw because **(1)** straw is a natural building material and renewable resource, **(2)** there is a surplus of straw after harvesting grains such as wheat (which I used), oats, barley, and rice, **(3)** its insulation value of R-54 comes in handy when you live in an area where winter temperatures can dip to 40°F below zero, and **(4)** they are easy to build (with only 1 week needed to put up the strawbale walls). Since the 1980s strawbale houses have also been built in Arizona and New Mexico to beat the heat.

I used a passive solar design by orienting the house to the south to take advantage of Colorado's abundant sunshine. During the day the insulated window covers are drawn up and the sun shines onto flagstone tiles covering a cement slab that stores and releases heat slowly to keep the house comfortably warm or cool regardless of outside conditions. At night the window covers are let down to hold the heat in.

Because I live in one of the world's sunniest places, I decided not to get hooked up to the electrical grid and instead get my electricity from a small wind turbine and panels of solar cells. The electricity is stored in a bank of 12 batteries and an inverter converts the stored direct current (DC) electricity to ordinary 120-volt alternating current (AC).

If it's cloudy and not windy for a couple of days (which is rare), I fire up a small gas generator to charge the batteries. I also use some propane to provide hot water with a small on-demand water heater. Only a small pilot light stays lit until the hot water faucet is turned on. Then a large flame is ignited that the water is piped through. This way, I do not use energy to keep a tank of water hot around the clock.

I use many energy-saving devices. They include compact florescent light bulbs, an oversized pressure tank so the well pump does not have to kick on every time the faucet turns on, and a superinsulated energy-efficient DC refrigerator.

I use organic gardening to grow flowers, herbs, and vegetables for my own use and for sale to local residents and restaurants. I incorporate some pioneering organic gardening techniques such as Rudolph Steiner's biodynamics (developed in 1924) and Bill Mollison's permaculture (developed in 1978).

Insect pests are picked off by hand and beneficial insects such as ladybugs are used to eat harmful insects such as aphids. Compost, aged animal manure, and cover crops that are plowed in as green manure are used to add nutrients to the soil. Crop rotation is used so as not to deplete the soil of nutrients.

Cold frames (a type of mini-greenhouse) are used to extend the growing season to 150 days in the cold climate where there are only about 90 days without a killing frost. My latest endeavor is building a passively heated strawbale greenhouse to provide the community with fresh salad greens, herbs, and flowers all winter long. The chicken coop is in the northeast corner of the greenhouse, with the heat given off by the chickens helping to warm the greenhouse.

My next venture is to start a nonprofit, Round Mountain Sustainable Living Institute, to educate people on how they can live in harmony with the earth.

Critical Thinking

Would you like to live a lifestyle similar to that of Nancy Wicks? Explain. Why do you think more people do not try to live more sustainably, as she does? List three ways to help encourage people to adopt such a lifestyle.

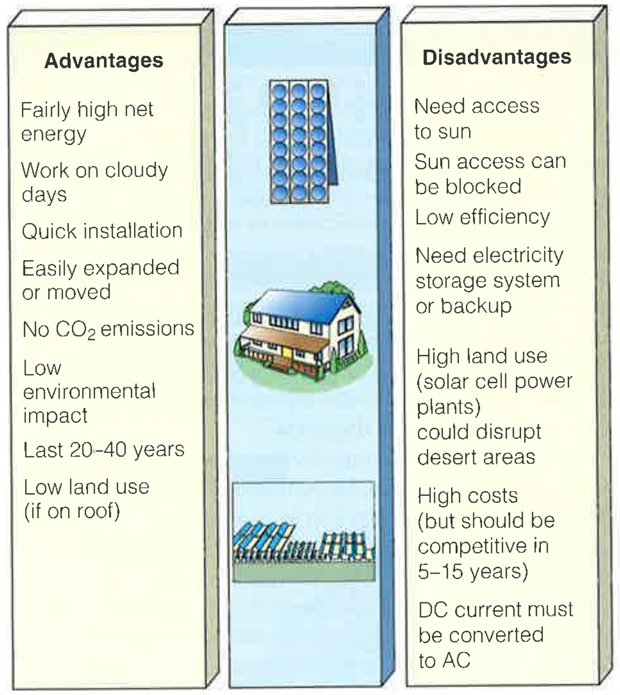


Figure 15-25 Advantages and disadvantages of using solar cells to produce electricity.

energy systems on 1 million roofs in the United States by 2010. Similar government-supported programs are expected to install 100,000 solar-cell roofs in Japan and Germany and 10,000 in Italy. Such programs can stimulate the mass production of solar cells that could reduce their costs by 75% or more.

Figure 15-25 lists the advantages and disadvantages of solar cells. With an aggressive program, analysts project that solar cells could supply 17% of the world's electricity by 2020—as much as nuclear power does today—at a lower cost and much lower risk. With a strong push from governments and private investors, by 2050 solar cells could provide as much as 25% of the world's electricity and at least 35% of the electricity in

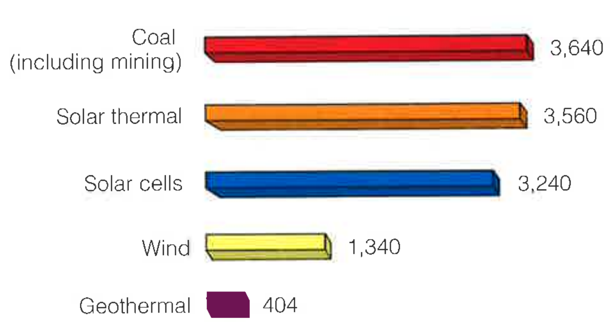


Figure 15-26 Approximate land use of various systems for producing electricity in the United States. Numbers give the land occupied in square meters per gigawatt-hour of electricity produced for 30 years. (Data from Worldwatch Institute)

the United States. If such projections are correct, the production, sale, and installation of solar cells (already a $2-billion-per-year business) could become one of the world's largest and fastest-growing businesses.

Critics of solar energy contend that producing electricity using large banks of solar cells, solar thermal plants (Figure 15-21b), and wind farms (photo, table of contents, p. xxiii, and Figure 15-29, p. 381) uses too much land. However, these three ways of producing electricity use less land per unit of electricity produced than coal (including the land disrupted from coal mining), the most widely used method for producing electricity (Figure 15-26).

15-4 PRODUCING ELECTRICITY FROM MOVING WATER AND FROM HEAT STORED IN WATER

How Can We Produce Electricity Using Hydropower Plants? Electricity can be produced from flowing water by:

- *Large-scale hydropower*, in which a high dam is built across a large river to create a reservoir (Figure 13-9, p. 301). Some of the water stored in the reservoir is allowed to flow through huge pipes at controlled rates, spinning turbines and producing electricity.
- *Small-scale hydropower*, in which a low dam with no reservoir (or only a small one) is built across a small stream and the stream's flow of water is used to spin turbines and produce electricity.
- *Pumped-storage hydropower*, in which pumps using surplus electricity from a conventional power plant pump water from a lake or a reservoir to another reservoir at a higher elevation. When more electricity is needed, water in the upper reservoir is released, flows through turbines, and generates electricity on its return to the lower reservoir.

Hydropower supplies about **(1)** 6% of the world's total commercial energy (4% in the United States) and **(2)** 20% of the world's electricity (10% in the United States but about 63% of the power used along the West Coast). Hydropower supplies about 99% of the electricity in Norway, 75% in New Zealand, 50% in developing countries, and 25% in China.

According to a 1999 study by Resources for the Future, the average cost for hydropower in the United States is 4¢ per kilowatt-hour, compared to **(1)** 3.5–6¢ for natural gas, **(2)** 3.5–5¢ for wind (down from 40¢ in 1980), **(3)** 4–7¢ for geothermal, **(4)** 5–6¢ for coal, **(5)** 10–21¢ for nuclear power, and **(6)** 20¢ using solar cells (although these costs are expected to fall sharply over the next 10–20 years).

Figure 15-27 lists the advantages and disadvantages of using large-scale hydropower plants to produce electricity. According to the United Nations, only about 13% of the world's technically exploitable potential for hydropower has been developed, with much of this untapped potential in South Asia (especially China, p. 301), South America, and parts of the former Soviet Union. However, because of increasing concern about the environmental and social consequences of large dams (Figure 13-9, p. 301), there has been growing pressure on the World Bank and other development agencies to stop funding new large-scale hydropower projects. In 2000, the World Commission on Dams published a study indicating that hydropower is a major emitter of greenhouse gases. This is because reservoirs that power the dams can trap rotting vegetation, which can emit greenhouse gases such as CO_2 and CH_4.

Small-scale hydropower projects eliminate most of the harmful environmental effects of large-scale projects, but they can **(1)** threaten recreational activities and aquatic life, **(2)** disrupt the flow of wild and scenic rivers, and **(3)** destroy wetlands. In addition, their electrical output can vary with seasonal changes in stream flow.

Is Producing Electricity from Tides and Waves a Useful Option? Twice a day in high and low tides,

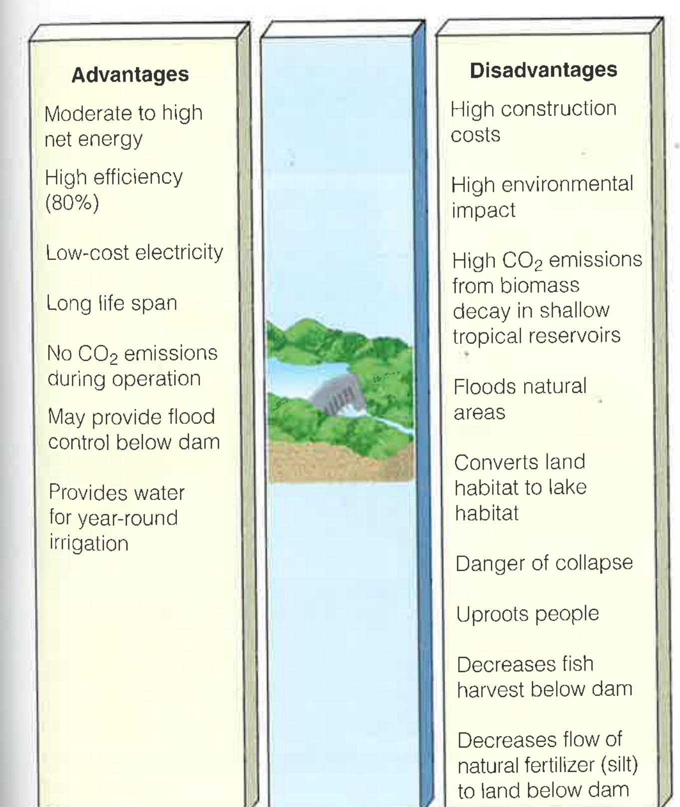


Figure 15-27 Advantages and disadvantages of using large dams and reservoirs to produce electricity.

water that flows into and out of coastal bays and estuaries can spin turbines to produce electricity (Figure 15-28a). Two large tidal energy facilities are currently operating, one at La Rance in France and the other in Canada's Bay of Fundy. However, most analysts expect tidal power to make only a tiny contribution to world electricity supplies. There are few suitable sites, and construction costs are high.

The kinetic energy in ocean waves, created primarily by wind, is another potential source of electricity (Figure 15-28b). Most analysts expect wave power to make little contribution to world electricity production, except in a few coastal areas with the right conditions (such as western England). Construction costs are moderate to high and the net energy yield is moderate, but equipment can be damaged or destroyed by saltwater corrosion and severe storms.

How Can We Produce Electricity from Heat Stored in Water? Japan and the United States have been evaluating the use of the large temperature differences (between the cold, deep waters and the sun-warmed surface waters) of tropical oceans for producing electricity. If economically feasible, this would be done in *ocean thermal energy conversion* (OTEC) plants anchored to the bottom of tropical oceans in suitable sites (Figure 15-28c). However, most energy analysts believe that the large-scale extraction of energy from ocean thermal gradients may never compete economically with other energy alternatives.

Saline solar ponds, usually located near inland saline seas or lakes in areas with ample sunlight, can be used to produce electricity (Figure 15-28d). Heat accumulated during the day in the denser bottom layer can be used to produce steam that spins turbines, generating electricity. A small experimental saline solar pond power plant on the shore of the Israeli side of the Dead Sea operated for several years but was closed in 1989 because of high operating costs.

Freshwater solar ponds can be used to heat water and space (Figure 15-28e). A shallow hole is dug and lined with concrete. A number of large, black plastic bags, each filled with several centimeters of water, are placed in the hole and then covered with fiberglass insulation panels. The panels let sunlight in but keep most of the heat stored in the water during the daytime from being lost to the atmosphere. When the water in the bags has reached its peak temperature in the afternoon, a computer turns on pumps to transfer hot water from the bags to large, insulated tanks for distribution.

Saline and freshwater solar ponds use no energy storage and backup systems, emit no air pollution, and have a moderate net energy yield. Freshwater solar ponds can be built in almost any sunny area and have moderate construction and operating costs.

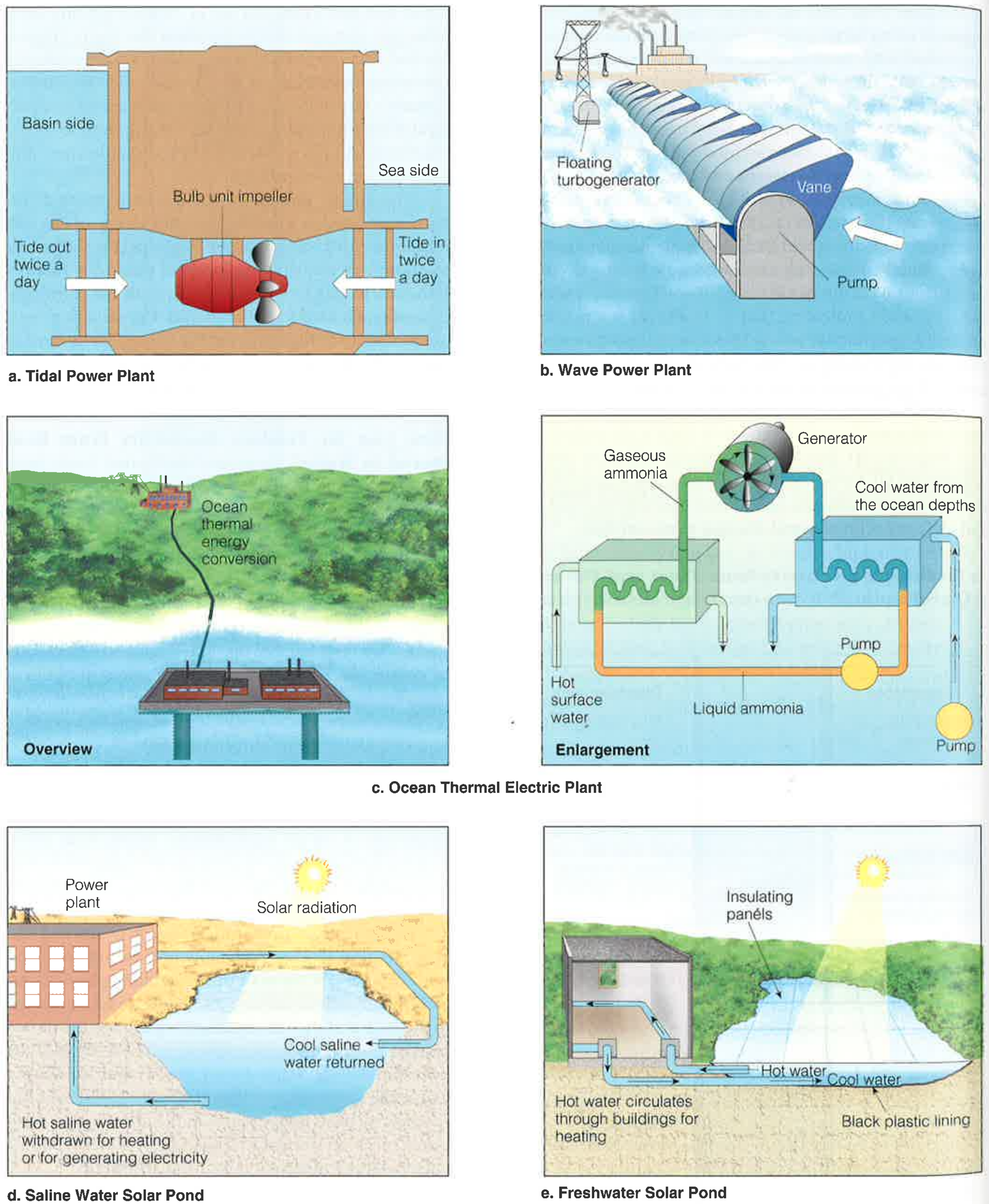


Figure 15-28 Ways to produce electricity from moving water and to tap into solar energy stored in water as heat. None of these systems are expected to be significant new sources of energy in the near future.

15-5 PRODUCING ELECTRICITY FROM WIND

How Rapidly Has the Use of Wind Power Grown? Wind power is the world's fastest-growing energy resource (with an average growth of 22% per year during the 1990s and more than $2 billion in sales of wind turbines in 2000). In 2000, wind turbines (Figure 15-29) worldwide produced almost 15,000 megawatts of electricity, enough to meet the needs of 5.2 million homes. This was more than three times the capacity in 1995 and 1,300 times the capacity in 1980.

Despite its rapid growth, wind power produced only about 1% of the energy used in the United States in 2000 because it is still in its infancy. However, the U.S. Department of Energy has launched a program designed to have 5% of the country's energy produced by the wind by 2020.

How Much Does It Cost to Produce Electricity from Wind? Between 1980 and 2000, the price of electricity produced by wind in the United States fell from 40¢ to 3.5–5¢ per kilowatt-hour, about the same as for new gas- and coal-fired power plants. According to the Department of Energy, with increased government funding for research and development and tax credits, the cost could fall to 2.5¢ within 3–5 years, making it the country's cheapest way to produce electricity.

What Areas Have the Greatest Potential for Wind Power? Figure 15-30 shows the potential areas for use of wind power in the United States. The U.S. Department of Energy calls the Midwestern United States the "Saudi Arabia of wind." The Dakotas and Texas alone have enough wind resources to meet all the nation's electricity needs. Sizable wind farm projects are being developed in 12 states, with the world's largest single wind project now being developed in Iowa. Individuals can also use small wind turbines to supply some or all of their electricity (Guest Essay, p. 377).

Currently, California has the largest number of wind turbines, which produce about 1.5% of the state's electricity—enough to power about 300,000 homes. However, California ranks 17th among states with the best future potential for wind power because most of its best sites have already been developed.

The global potential for wind power has barely been tapped. Inland China's Inner Mongolia has enough wind resources to provide all the country's electricity, and England also has an enormous potential supply of wind resources. Denmark (with wind generating more than 8% of its electricity) is the world's largest user of wind and producer of wind turbines. Wind power also is being developed rapidly in Germany (the world's third largest user of wind power), Spain, and India (the world's number-two market for wind energy).

In the long run, electricity from large wind farms in remote areas might be used to make hydrogen gas from water during off-peak periods. The hydrogen could then be fed into a pipeline and storage system.

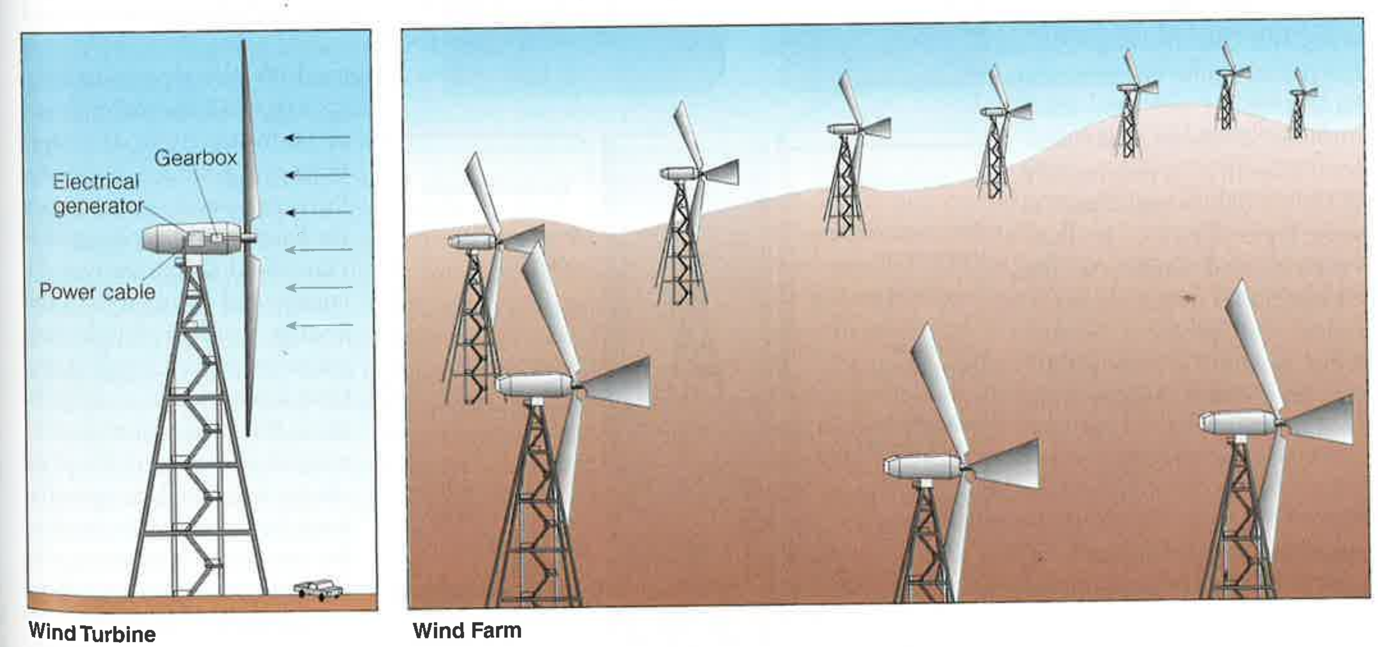


Figure 15-29 Wind turbines can be used to produce electricity individually or in clusters called wind farms.

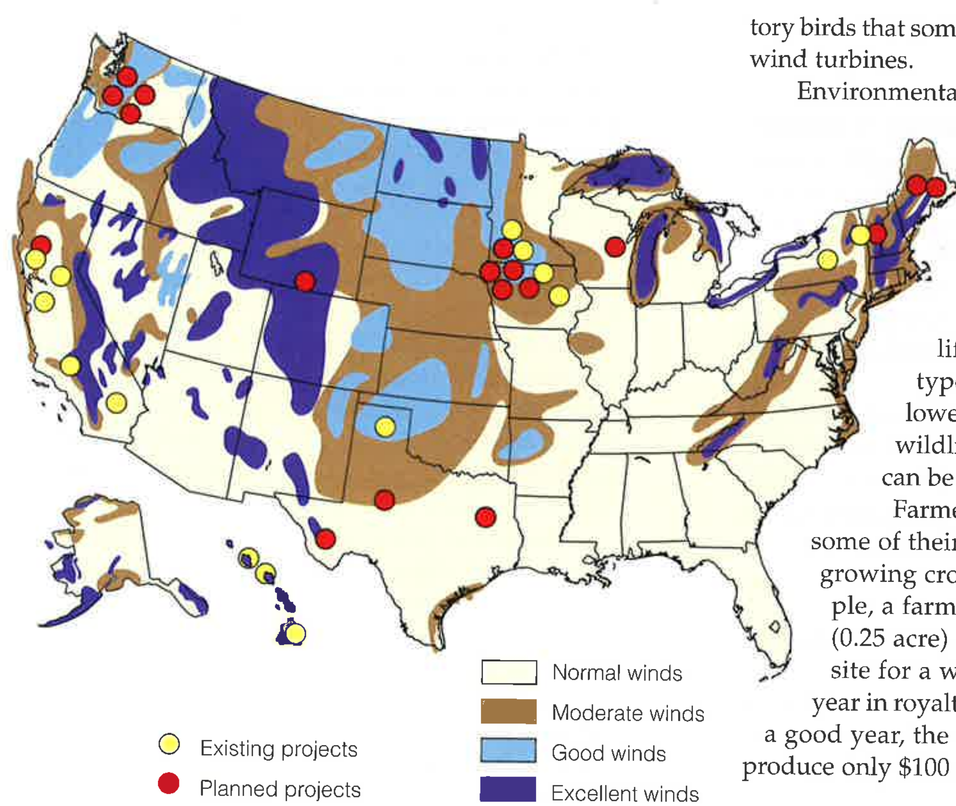


Figure 15-30 Potential for use of wind power in the United States. In principle, all the power needs of the United States could be provided by exploiting the wind potential of just three states: North Dakota, South Dakota, and Texas. (Data from U.S. Department of Energy)

What Are the Major Advantages and Disadvantages of Wind Power? Figure 15-31 lists the advantages and disadvantages of using wind to produce electricity. Some environmentalists and other critics have pointed out that wind turbines have been responsible for the death of approximately 10,000 predatory birds (such as some types of hawks, kestrels, vultures, and eagles) in the United States over the past 20 years. The problem is that wind turbine towers attract bird prey, which attract predatory birds that sometimes get caught in the blades of the wind turbines.

Environmentalists and wind turbine manufacturers are working on this problem. Oil spills, air pollution, water pollution, and release of toxic wastes from use of fossil fuels such as coal and oil have also killed enormous numbers of birds, fish, and other forms of wildlife. The key questions are **(1)** which types of energy resources lead to the lowest loss of wildlife and **(2)** how loss of wildlife from use of any energy resource can be minimized.

Farmers can boost their income by leasing some of their cropland for wind turbines, while growing crops around the turbines. For example, a farmer in Iowa who leases 0.10 hectare (0.25 acre) of cropland to the local utility as a site for a wind turbine typically gets $2,000 a year in royalties from the electricity produced. In a good year, the site occupied by the turbine could produce only $100 worth of corn.

Advantages	Disadvantages
Moderate to high net energy	Steady winds needed
High efficiency	Backup systems when needed winds are low
Moderate capital cost	High land use for wind farm
Low electricity cost (and falling)	Visual pollution
Very low environmental impact	Noise when located near populated areas
No CO_2 emissions	May interfere in flights of migratory birds and kill birds of prey
Quick construction	
Easily expanded	

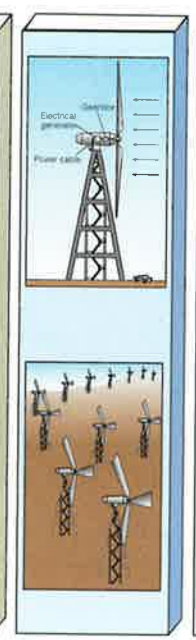


Figure 15-31 Advantages and disadvantages of using wind to produce electricity. Wind power experts project that by 2050 wind power could supply more than 10% of the world's electricity and 10–25% of the electricity used in the United States.

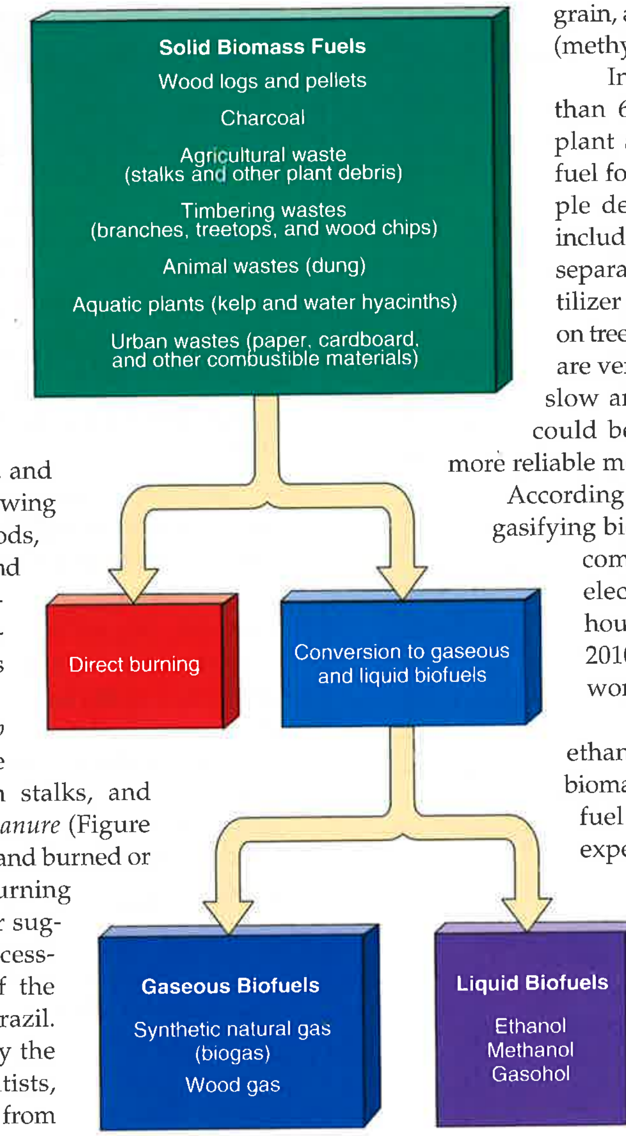
15-6 PRODUCING ENERGY FROM BIOMASS

How Useful Is Burning Solid Biomass? Biomass is plant materials and animal wastes used as sources of energy. Biomass comes in many forms and can be burned directly as a solid fuel or converted into gaseous or liquid **biofuels** (Figure 15-32).

Most biomass is burned **(1)** directly for heating, cooking and industrial processes or **(2)** indirectly to drive turbines and produce electricity. Burning wood and manure for heating and cooking supplies about 12% of the world's energy and about 30% of the energy used in developing countries. In the United States, biomass is used to supply about 4% of the country's commercial energy and 2% of its electricity. The U.S. government has a goal of increasing the use of biomass energy to 9% of the country's total commercial energy by 2010.

Almost 70% of the people living in developing countries heat their homes and cook their food by burning wood or charcoal. However, about 2.7 billion people in these countries cannot find (or are too poor to buy) enough fuelwood to meet their needs.

Figure 15-32 Principal types of biomass fuel.



One way to produce biomass fuel is to plant, harvest, and burn large numbers of fast-growing **(1)** trees (especially cottonwoods, poplars, sycamores, willows, and leucaenas), **(2)** shrubs, **(3)** perennial grasses (such as switchgrass), and **(4)** water hyacinths in *biomass plantations.*

In agricultural areas, *crop residues* (such as sugarcane residues, rice husks, cotton stalks, and coconut shells) and *animal manure* (Figure 23-22, p. 612) can be collected and burned or converted into biofuels. Burning *bagasse*—the residue left after sugarcane harvesting and processing—supplies about 10% of the electricity in Hawaii and in Brazil. According to a 1999 study by the Union of Concerned Scientists, energy crops and crop wastes from the Midwest alone could theoretically provide about 16% of the electricity used in the United States, without irrigation and without competing with food crops for land.

Some ecologists argue that it makes more sense to use animal manure as a fertilizer and crop residues to feed livestock, retard soil erosion, and fertilize the soil. Figure 15-33 lists the general advantages and disadvantages of burning solid biomass as a fuel. One problem is that burning biomass produces carbon dioxide. However, if the rate of use of biomass does not exceed the rate at which it is replenished by new plant growth (which takes up CO_2), there is no net increase in CO_2 emissions.

Is Producing Gaseous and Liquid Fuels from Solid Biomass a Useful Option? Bacteria and various chemical processes can convert some forms of biomass into gaseous and liquid biofuels (Figure 15-32). Examples include **(1)** *biogas*, a mixture of 60% methane and 40% carbon dioxide, **(2)** *liquid ethanol* (ethyl, or grain, alcohol), and **(3)** and *liquid methanol* (methyl, or wood alcohol).

In China, anaerobic bacteria in more than 6 million *biogas digesters* convert plant and animal wastes into methane fuel for heating and cooking. These simple devices can be built for about $50 including labor. After the biogas has been separated, the solid residue is used as fertilizer on food crops or, if contaminated, on trees. When they work, biogas digesters are very efficient. However, they are also slow and unpredictable, a problem that could be corrected with development of more reliable models.

According to the U.S. Department of Energy, gasifying biomass and burning it in advanced combustion turbines could produce electricity costing 4.5¢ per kilowatt-hour by 2010. Shell Oil projects that by 2010 biomass could provide 5% of the world's electricity (worth $20 billion).

Some analysts believe that liquid ethanol and methanol produced from biomass could replace gasoline and diesel fuel when oil becomes too scarce and expensive. *Ethanol* can be made from sugar and grain crops (sugarcane, sugar beets, sorghum, sunflowers, and corn) by fermentation and distillation. Gasoline mixed with 10-23% pure ethanol makes *gasohol,* which can be burned in conventional gasoline engines and is sold as super unleaded or ethanol-enriched gasoline.

Another alcohol, *methanol*, is made mostly from natural gas but also can be produced at a higher cost from wood, wood wastes, agricultural wastes (such as corncobs), sewage sludge, garbage, and coal. Some of the first generation of cars using hydrogen-powered fuel cells will use reformers to convert methanol to hydrogen. The advantages and disadvantages of using ethanol, methanol, and several other fuels as alternatives to gasoline are summarized in Table 15-1, p. 385. According to a 1997 analysis by David Pimentel and two other researchers, "Large-scale biofuel production is not an alternative to the current use of oil and is not even an advisable option to cover a significant fraction of it."

Projections about the future role of biomass energy vary widely, with this resource providing 14–40% of the world's energy by 2050 depending on assumptions about **(1)** biomass gasification, **(2)** use in energy-efficient fuel cells, and **(3)** establishment of biomass plantations on degraded forestland and idle cropland.

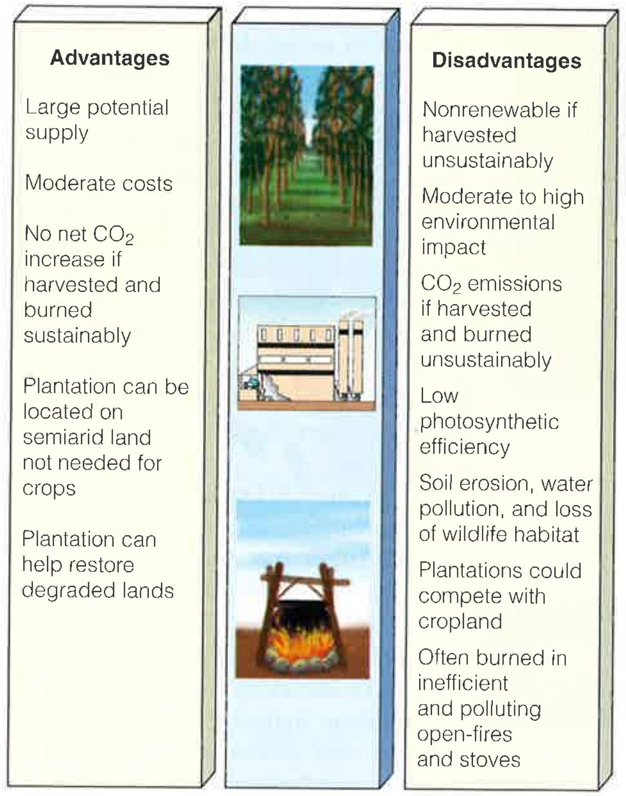


Figure 15-33 General advantages and disadvantages of burning solid biomass as a fuel.

Whether such a projection becomes reality depends on **(1)** the availability of large areas of productive land and adequate water (resources that may be in short supply in coming decades), **(2)** the ability to minimize the harmful environmental effects of large-scale biomass production, and **(3)** whether biomass is used sustainably so that there is no net increase in CO_2 emissions.

15-7 THE SOLAR-HYDROGEN REVOLUTION

What Can We Use to Replace Oil? Good-Bye Oil and Smog, Hello Hydrogen When oil is gone (or when what's left costs too much to use), what will we use to fuel vehicles, industry, and buildings? Many scientists and executives of major oil companies and automobile companies say the fuel of the future is hydrogen gas (H_2) (Table 15-1, right).

When hydrogen gas burns in air, it combines with oxygen gas in the air and produces nonpolluting water vapor* and some nitrogen oxides (produced because air, which is 78% nitrogen, is used to burn hydrogen). This eliminates most of the air pollution problems we face today and greatly reduces the threats from global warming by emitting no carbon dioxide.

There is very little hydrogen gas (H_2) around. Instead, it is combined with other elements in compounds such as water, most organic compounds such as methane (CH_4) and methanol (CH_3OH), and those found in oil and gasoline. Methods for producing hydrogen include the following:

- *Reforming*, in which chemical processes are used to separate hydrogen from carbon atoms in organic compounds such as methane (CH_4) or methanol (CH_3OH).
- *Electrolysis of water*, in which direct electrical current is passed through water to convert its molecules into gaseous hydrogen and oxygen (Figure 15-34).
- *Photoelectrolysis*, in which electricity produced by solar cells (Figure 15-23) is used to split water molecules into gaseous hydrogen and oxygen. In 2000, researchers at the Isreal Institute of Technology created a combined *photovoltaic–photoelectrochemical cell* that uses sunlight to split water into hydrogen and oxygen at an efficiency of 18.3%. The researchers believe that such systems are capable of reaching a conversion efficiency of over 30%.
- *Coal gasification* (Figure 14-30, p. 345).
- *Biomass gasification*, in which wood chips and agricultural wastes are superheated to turn them into hydrogen and other gases.
- *Thermolysis*, in which high temperatures (up to 3000°C) are used to split water molecules into H_2 and O_2.
- *Biological production*, in which some types of algae and bacteria use sunlight to produce hydrogen under certain conditions (Spotlight, p. 387).

What Is the Catch? If you think using hydrogen as an energy source sounds too good to be true, you're right. Several problems must be solved to make hydrogen one of our primary energy resources, but scientists are making rapid progress in finding solutions to these problems.

One problem is that it takes energy (and thus money) to produce this fuel. We could burn coal to produce high-temperature heat or use electricity from coal-burning and nuclear power plants to split water and produce hydrogen. However, this subjects us to the harmful environmental effects associated with using these fuels (Chapter 14), and it costs more than the hydrogen fuel is worth.

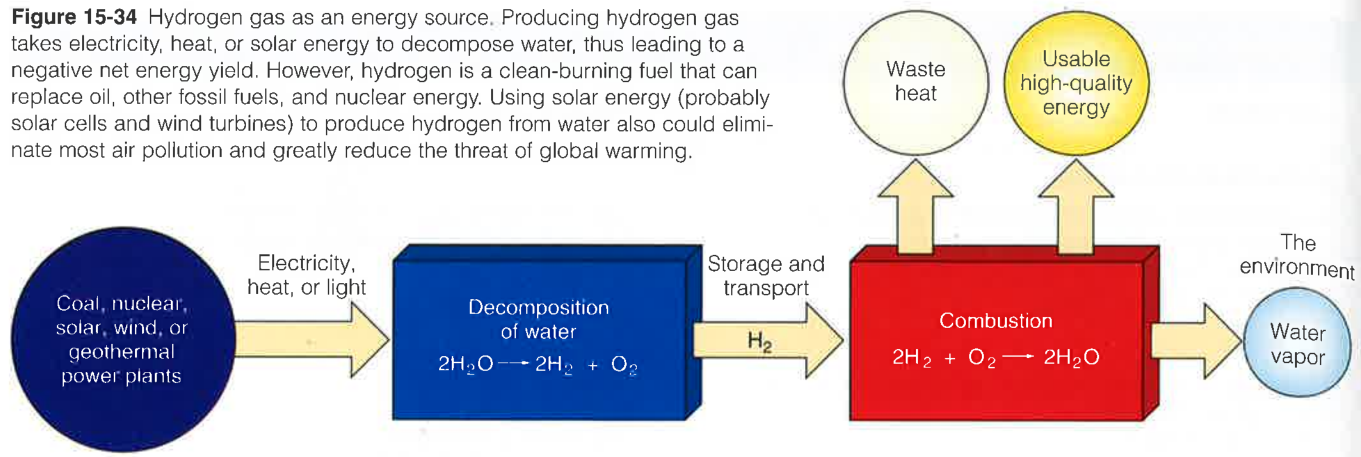
Most proponents of using hydrogen gas believe that if we are to get its very low pollution benefits, the

*Water vapor is a potent greenhouse gas. However, because there is already so much of it in the atmosphere, human additions of this gas are insignificant.

Table 15-1 Evaluation of Alternatives to Gasoline

Advantages	Disadvantages
Compressed Natural Gas	
Fairly abundant, inexpensive domestic and global supplies Low hydrocarbon, CO, and CO_2 emissions Vehicle development advanced; well suited for fleet vehicles Reduced engine maintenance	Large fuel tank needed; one-fourth the range Expensive engine modification needed ($2,000) New filling stations needed Nonrenewable resource
Electricity	
Renewable if not generated from fossil fuels or nuclear power Zero vehicle emissions Electric grid in place Efficient and quiet	Limited range and power Batteries expensive Slow refueling (6–8 hours) Power plant emissions if generated from coal or oil
Reformulated Gasoline (Oxygenated Fuel)	
No new filling stations needed Low to moderate CO emissions reduction No engine modification needed	Nonrenewable resource Dependence on imported oil perpetuated No CO_2 emission reduction Higher cost Groundwater contaminated by leakage and spills (especially by MTBE, a possible human carcinogen) No longer needed because of improved emission control system
A-55 (55% water, 45% naphtha)	
Can be sold in conventional filling station Much lower emissions of nitrogen oxide and particulates than diesel fuel Cannot explode or catch fire Lower cost (25–50%) Naphtha produces 90% less pollution at refineries than gasoline or diesel fuel Low-cost engine modification ($300 for cars, $1000 for trucks and buses Modified engine can run A-55, gasoline of diesel	Not yet widely available Independent tests needed to verify pollution reduction claims Refineries may limit supply or drive up price of less-profitable naphtha Large amounts of water needed to produce
Methanol	
High octane Reduction of CO_2 emissions (total amount depends on method of production) Reduced total air pollution (30–40%)	Large fuel tank needed; one-half the range Corrosive to metal, rubber, plastic Increased emissions of potentially carcinogenic formaldehyde High CO_2 emissions if generated by coal High capital cost to produce Hard to start in cold weather
Ethanol	
High octane Reduction of CO_2 emissions (total amount depends on distillation process and efficiency of crop growing) Reduction of CO emissions Potentially renewable	Large fuel tank needed; lower range Much higher cost Corn supply limited Competition with food growing for cropland Smog formation possible Corrosive Hard to start in cold weather
Solar–Hydrogen	
Renewable if produced using solar energy Lower flammability than gasoline Virtually emission-free No emissions of CO_2 Nontoxic	Nonrenewable if generated by fossil fuels or nuclear power Large fuel tank needed No distribution system in place Engine redesign needed Currently expensive

Figure 15-34 Hydrogen gas as an energy source. Producing hydrogen gas takes electricity, heat, or solar energy to decompose water, thus leading to a negative net energy yield. However, hydrogen is a clean-burning fuel that can replace oil, other fossil fuels, and nuclear energy. Using solar energy (probably solar cells and wind turbines) to produce hydrogen from water also could eliminate most air pollution and greatly reduce the threat of global warming.



energy to produce the gas from water must come from the sun, probably **(1)** in the form of electricity generated by sources such as hydropower, solar cells, solar thermal power plants (Figure 15-21b, p. 374), and wind farms and **(2)** perhaps eventually from bacteria and algae (Spotlight, right).

If scientists and engineers can learn how to use sunlight to decompose water cheaply enough, they will set in motion a *solar-hydrogen revolution* over the next 50 years and change the world as much as the agricultural and industrial revolutions did. Currently, using solar energy to produce hydrogen gas is too costly, but the costs of using solar energy to produce electricity are coming down. The goal of the Department of Energy is to have the cost of hydrogen equal to that of natural gas by 2030.

The first widespread use of hydrogen probably will be to combine it with gasoline, ethanol, methanol, and natural gas to increase fuel performance and reduce air pollution. Adding just 5% hydrogen to gasoline can reduce emissions of nitrogen oxides (NO and NO_2) by 30–40%.

Next, blends of natural gas and hydrogen produced by solar-cell or thermal solar power plants (in sunny, mostly desert areas) or wind turbines could be mixed with natural gas or carried alone in modified natural gas pipelines to users. Researchers estimate that using pipelines to transport hydrogen long distances should cost only about one-fourth as much as transmitting electricity the same distance.

Once produced, hydrogen must be stored for use in cars, furnaces, air conditioners, or fuel cells. Hydrogen can be stored:

- In *compressed gas storage tanks*. The technology is available, but the costs of tanks and compression are high, and tanks are too heavy for use in motor vehicles.
- *As liquid hydrogen*. Condensing hydrogen gas into more dense liquid form allows a larger quantity of hydrogen to be stored and transported. However, this conversion takes a large input of energy and is costly.
- *As solid metal hydride compounds*, which when heated decompose and release hydrogen gas. This is a safe and efficient way to store hydrogen, but an input of energy is needed to release the hydrogen.
- *By absorption on activated charcoal*, which when heated releases hydrogen gas. Like hydrides, this is a safe and efficient way to store hydrogen, but an input of energy is needed to release the hydrogen.
- *Inside glass microspheres*. Currently, tiny glass spheres are being developed for this purpose.

Unlike gasoline, metal hydrides, charcoal powders, and glass microspheres containing hydrogen will not explode or burn if a vehicle's tank is ruptured in an accident. However, it's difficult to store enough hydrogen gas in a car as a compressed gas, liquid, or a solid for it to run very far, a problem similar to the one the electric car faces. Scientists and engineers are seeking solutions to this problem.

Another possibility is to power a car with a *fuel cell* (Figures 15-4 and 15-10) in which hydrogen and oxygen gas combine to produce electrical current. Fuel cells produce no air pollution and have energy efficiencies of 65–95%, several times the efficiency of conventional gasoline-powered engines and electric cars.

A number of prototype fuel-cell systems for cars, buses, homes, and buildings are being tested and evaluated. All major automobile companies have developed fuel-cell cars (Figure 15-10) and hope to begin marketing them by 2004. In 1999, DaimlerChrysler and Shell announced plans to turn the tiny country of Iceland into the world's first "hydrogen economy," eventually replacing the gasoline and diesel engines on all its cars, buses, and fishing vessels with hydrogen.

Two U.S. companies are developing residential fuel cells that use methane to produce hydrogen fuel for the cell. These units are about the size of a dishwasher,

Producing Hydrogen from Green Algae Found in Pond Scum

SPOTLIGHT

In a few decades we may be able to use large-scale cultures of green algae to produce hydrogen gas. This simple plant grows all over the world and is commonly found in pond scum.

When living in ordinary air and sunlight, green algae carry out photosynthesis like other plants and produce carbohydrates and oxygen gas. However, in 2000, Tasios Melis, a researcher at the University of California, Berkeley, found a way to make these algae produce bubbles of hydrogen rather than oxygen.

First, he grew cultures of hundreds of billions of the algae in the normal way with plenty of sunlight, nutrients, and water. Then he cut off their supply of a two key nutrients: sulfur and oxygen. Within 20 hours, the plant cells underwent a metabolic change and switched from an oxygen-producing to a hydrogen-producing metabolism, allowing the researcher to collect hydrogen gas bubbling from the culture.

Melis believes that he can increase the efficiency of this hydrogen-producing process tenfold. If so, sometime in the future a biological hydrogen plant might cycle an algae-water mixture through a system of clear tubes exposed to sunlight to produce hydrogen. The gene responsible for producing the hydrogen might even be transferred to other plants to produce hydrogen.

Critical Thinking

What might be some ecological problems related to the widespread use of this method for producing hydrogen?

should cost less than $4,000, and could be on the market by 2002. A single unit could supply all the heating, cooling, cooking, refrigeration, and electrical needs of a home and provide hydrogen fuel for one or more cars at an affordable price.

Figure 15-35 lists the pros and cons of using hydrogen as an energy resource. The Department of Energy has a goal of hydrogen energy providing 10% of all U.S.

Advantages	Disadvantages
Can be produced from water	Not found in nature
Low environmental impact	Energy is needed to produce fuel
No CO_2 emissions	Negative net energy
Good substitute for oil	High costs (but expected to come down)
Competitive price if environmental and social costs are included in cost comparisons	Short driving range for current fuel cell cars
Easier to store than electricity	
Safer than gasoline and natural gas	
High efficiency (65–95%) in fuel cells	

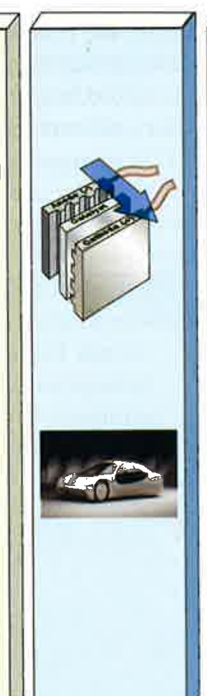


Figure 15-35 Advantages and disadvantages of using hydrogen as a fuel for vehicles and for providing heat and electricity.

energy consumption by 2025. Even if this is only partially accomplished, it could greatly reduce emissions of CO_2 and other air pollutants and decrease U.S. dependence on oil imports.

15-8 GEOTHERMAL ENERGY

How Can We Tap the Earth's Internal Heat? Going Underground **Geothermal energy** is energy extracted from the earth's internal heat. Under the earth's crust, there is a layer of hot and molten rock called magma in the earth's mantle (Figure 10-3, p. 213). Because it is less dense than the surrounding rock, magma rises slowly toward the earth's crust, carrying heat from below.

Sometimes the hot magma reaches the earth's surface as lava. However, most magma remains below earth's crust, heating nearby rock and groundwater. Some of this hot geothermal water travels up through *geysers*. However, most of it remains deep underground, trapped in cracks and porous rock. This natural collection of hot water is called a *geothermal reservoir*.

Heat, mostly from the radioactive decay of naturally radioactive elements, is continually transferred to underground reservoirs of **(1)** *dry steam* (steam with no water droplets), **(2)** *wet steam* (a mixture of steam and water droplets), and **(3)** *hot water* trapped in fractured or porous rock at various places in earth's crust.

If such geothermal reservoirs are close to the surface, wells can be drilled to extract the dry steam, wet steam (Figure 15-36), or hot water. This thermal energy can be used to heat homes and buildings and to produce electricity.

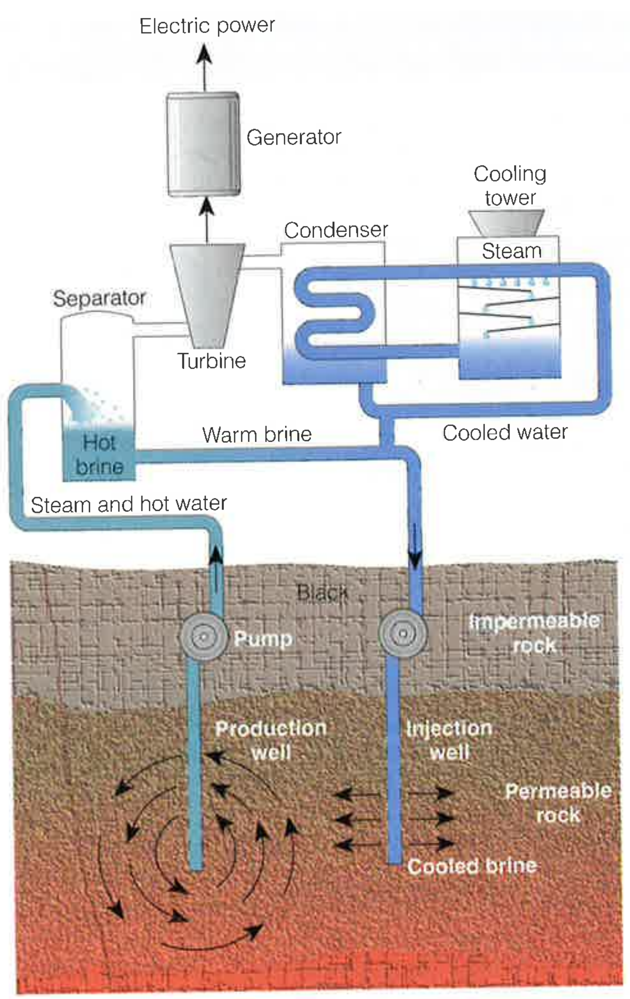


Figure 15-36 Tapping the earth's heat or geothermal energy in the form of wet steam to produce electricity.

However, these geothermal reservoirs can be depleted if heat is removed faster than natural processes renew it. Thus, geothermal resources can be nonrenewable on a human time scale, but the potential supply is so vast that it is usually classified as a renewable energy resource.

Figure 15-37 shows the locations of the world's known global reservoirs of moderate- to high-temperature geothermal energy. Currently, about 22 countries (most of them in the developing world) are extracting energy from geothermal sites to produce about 1% of the world's electricity.

The United States accounts for 38% of the 7,000 megawatts of geothermal electricity generated worldwide, with most of the favorable sites in California, Hawaii, Nevada, and Utah. The Philippines is the world's second largest user, followed by Mexico. In 1999, Santa Monica, California, became the first city in the world to get all its electricity from geothermal energy.

The world's largest operating geothermal system, called *The Geysers*, extracts energy from a dry steam reservoir north of San Francisco, California. Electricity production at this site began in 1960. Now the area contains 26 power plants producing enough power for a city of 1.3 million people. However, heat is being withdrawn from this geothermal site about 80 times faster than it is being replenished, converting this potentially renewable resource to a nonrenewable source of energy.

Geothermal water has been used to heat homes and buildings in Klamath Falls, Oregon, and Boise, Idaho, for more than a century. In Iceland, every building is heated by hot spring water.

Three other virtually nondepletable sources of geothermal energy are **(1)** *molten rock* (magma), **(2)** *hot dry-rock zones*, where molten rock that has penetrated the earth's crust heats subsurface rock to high temperatures, and **(3)** low- to moderate-temperature *warm-rock reservoir deposits*, which could be used to preheat water and run heat pumps for space heating and air conditioning. Research is being carried out in several countries to see whether hot dry-rock zones, which can be found almost anywhere about 8–10 kilometers (5–6 miles) below the earth's surface, can provide affordable geothermal energy.

Figure 15-38 lists the pros and cons of using geothermal energy. Currently, the cost of tapping geothermal energy is too high for all but the most concentrated and accessible sources. According to the U.S. Geothermal Energy Association, at best geothermal energy could meet 5% of all U.S. energy needs over the next several decades.

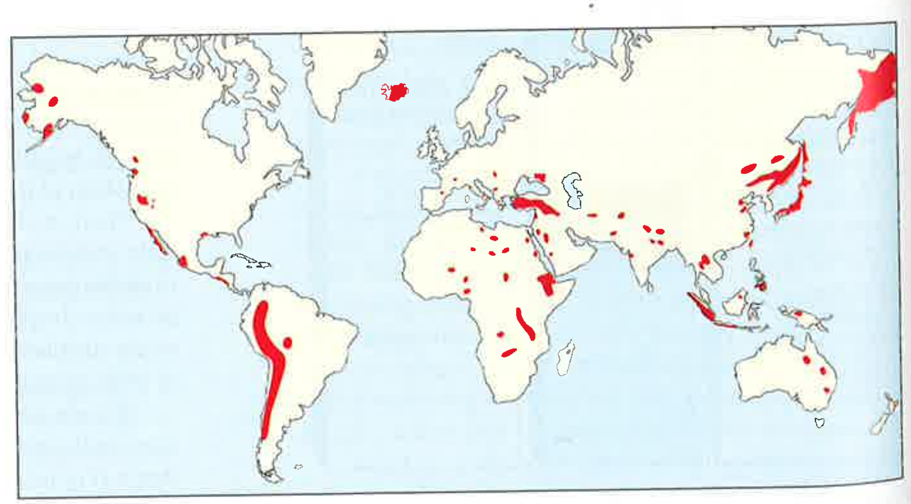


Figure 15-37 Known global reservoirs of moderate- to high-temperature geothermal energy. (Data from Canadian Geothermal Resources Council)

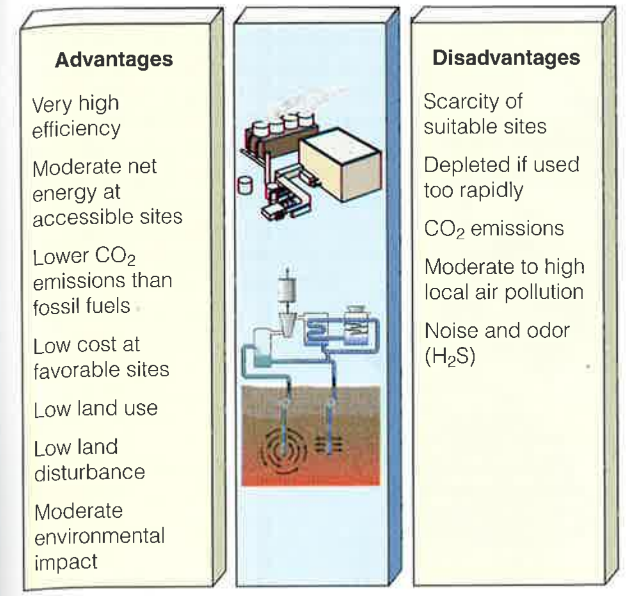


Figure 15-38 Advantages and disadvantages of using geothermal energy for space heating and to produce electricity or high-temperature heat for industrial processes.

15-9 ENTERING THE AGE OF DECENTRALIZED MICROPOWER

What Is Micropower? According to Chuck Linderman, director of energy supply policy for the Edison Electric Institute, the era of big central power-plant systems (Figure 15-39) is over. According to a growing number of energy and financial analysts, countries, companies, and investors trying to preserve or build large, centralized coal-burning and nuclear power plants may find themselves saddled with expensive technological dinosaurs.

Most energy analysts believe that the chief feature of electricity production over the next few decades is significant *decentralization* to dispersed, small-scale power systems (Figure 15-40). These **micropower systems** generate 1–10,000 kilowatts of power. This shift from centralized *macropower* to dispersed *micropower* is analogous to the computer industry's shift from large, centralized mainframes to increasingly smaller, widely dispersed PCs, laptops, and handheld computers.

In a special August 1999 issue of *Business Week* titled "21 Ideas for the 21st Century," the drastic downsizing of power-producing systems to micropower plants headed the list. Increasing amounts of venture capital and entrepreneurial talent in small startup energy companies and in large companies (such as General Electric, BP, and Shell Oil) are moving into this rapidly growing investment opportunity.

Between the mid-1960s and the mid-1980s, the average size of a new utility power station in the United States fell from 1,000,000 kilowatts (1 megawatt) to 600,000 kilowatts. Then between the mid-1980s and 1998 it fell again to an average of 210,000 kilowatts, the size of a typical natural gas combined-cycle power station.

This trend of power-plant downsizing is continuing with increased use of **(1)** moderate-size industrial cogeneration plants (50,000 kilowatts) and **(2)** energy-efficient, natural gas-burning gas generators (microturbines) for commercial buildings and residences (5–10,000 kilowatts). These microturbines are tiny jet engines that use heat released by combustion to spin a shaft that spins a high-speed generator. They can be fitted with lean burn engines and catalytic converters to reduce air pollution (mostly nitrogen oxides) and mufflers and soundproofing to reduce noise. Like central air conditioning units, they are serviced regularly by professionals.

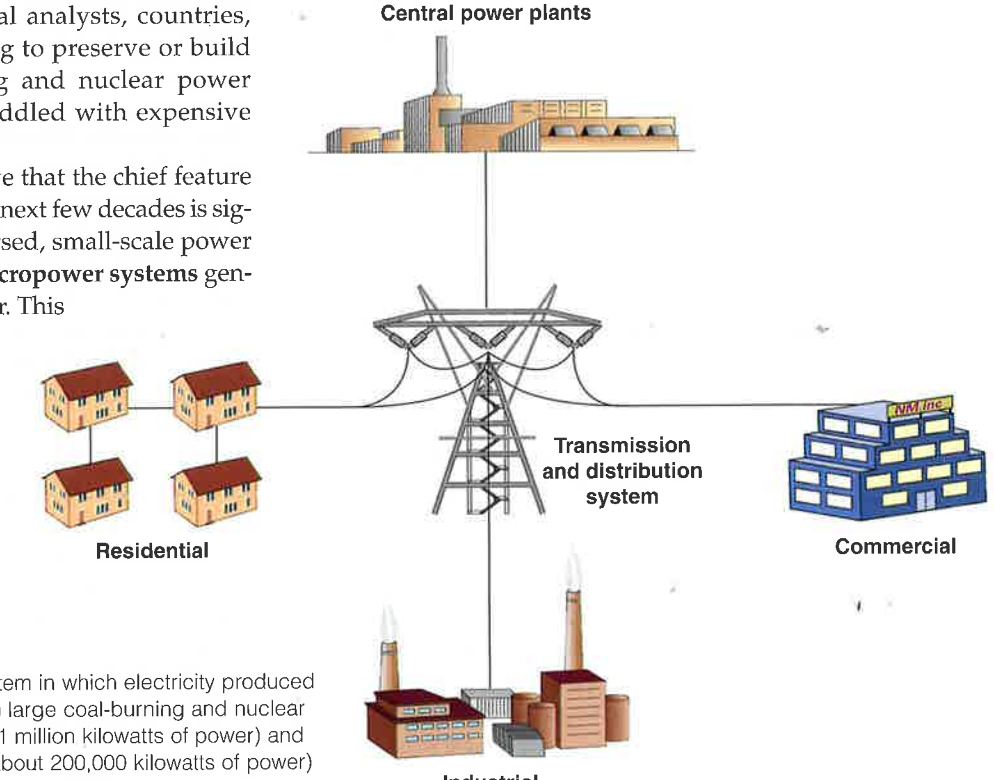


Figure 15-39 Centralized power system in which electricity produced mainly by a fairly small number of **(1)** large coal-burning and nuclear power plants (producing 600,000 to 1 million kilowatts of power) and **(2)** natural-gas turbines (producing about 200,000 kilowatts of power) is distributed by a system of high-voltage wires to users.

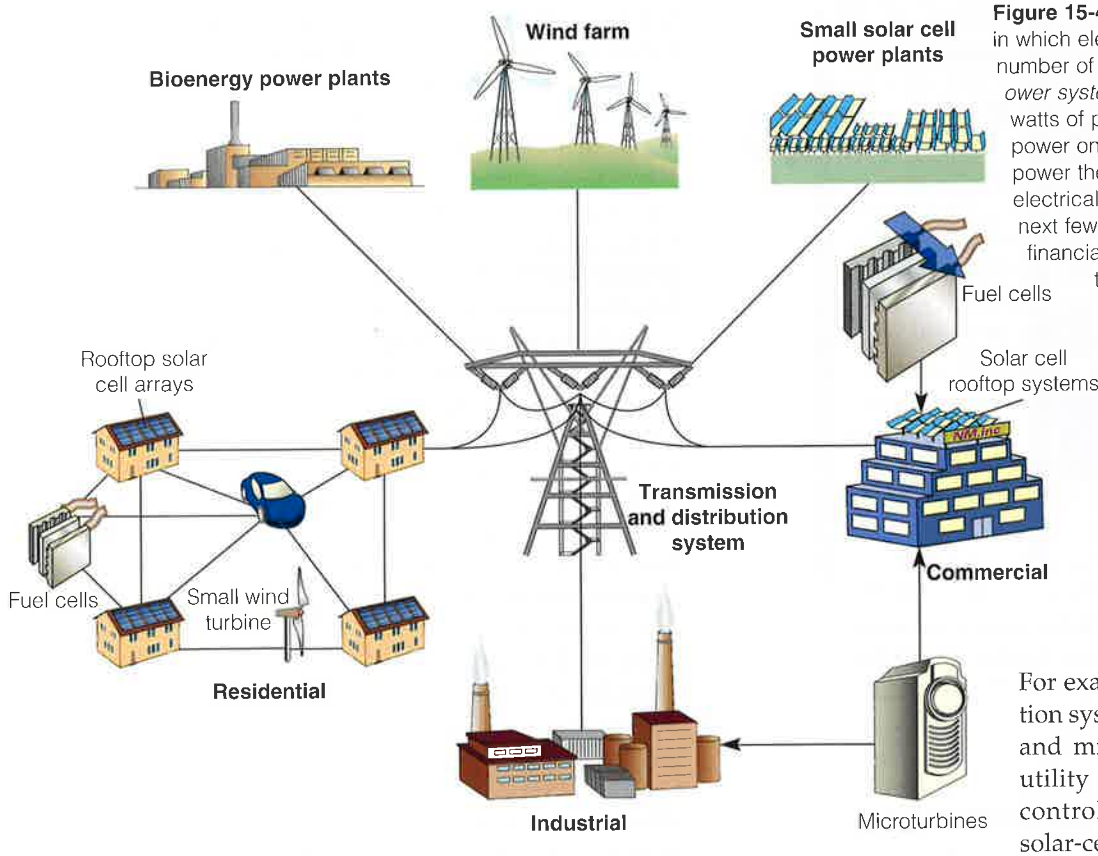


Figure 15-40 Decentralized power system in which electricity is produced by a large number of dispersed, small-scale *micropower systems* (producing 1–10,000 kilowatts of power). Some would produce power on site and others would feed the power they produce into a conventional electrical distribution system. Over the next few decades, many energy and financial analysts expect a shift to this type of power system.

This downsizing will be accelerated by the switch to increasingly smaller and more dispersed micropower systems such as **(1)** *wind turbines* (1–3,000 kilowatts), **(2)** low-cost *microturbines* for businesses (25–300 kilowatts), **(3)** energy-efficient *Stirling engines* (0.1–100 kilowatts), **(4)** efficient, quiet, reliable, low-maintenance *fuel cells* (1–10,000 kilowatts), and **(5)** quiet, reliable, low-maintenance household *solar panels and solar roofs* (1–1,000 kilowatts, Figure 15-23). Figure 15-41 lists some of the advantages of decentralized micropower systems (Figure 15-40) over traditional macropower systems (Figure 15-39).

How Can Decentralized Micropower Systems Be Managed? Some electric utility officials believe that a decentralized micropower system controlled mostly by customers instead of a centralized control system can lead to chaos. However, a growing number of energy analysts argue that by using multiple feedback loops integrated through a communication network, a decentralized, dispersed micropower system can be more resilient than a centralized system.

They envision using modern communication technologies to integrate centralized and decentralized power systems. As with the internet, individuals and businesses can use such a system to make their own power choices using a common set of connection rules or protocols.

For example, two-way communication systems using fiber-optic cables and microprocessors would allow utility companies to monitor and control the individual fuel cells, solar-cell rooftop systems, wind turbines, cogenerators, air conditioners, and water heaters of their customers. These communication systems could **(1)** turn such devices on or off (to save energy), **(2)** withdraw and buy excess power from customers, and **(3)** sell the power as needed. Controlled by computers, such an integrated system could maximize its overall energy efficiency and respond immediately to any problems.

How Rapidly Can the Transition to Micropower Be Made? No one knows how fast the transition to micropower systems can be made. However, much of the technology has already been developed, and investment capital is flowing rapidly into development and use of such systems. The potential for financial gain by companies and investors is huge, with a $10-trillion market projected for the global energy supply between 2000 and 2020. With the right economic stimulus and government policies, some analysts believe that micropower systems could dominate global markets for new power within 5–10 years.

Decentralized micropower systems could allow 2 billion people in isolated villages in developing countries to leapfrog over more expensive centralized power systems. Such villages could be powered by micropower systems such as **(1)** wind turbines and solar cells backed by fuel cells running on hydrogen produced from renewable sources and **(2)** Stirling engines and microturbines burning locally available biomass resources.

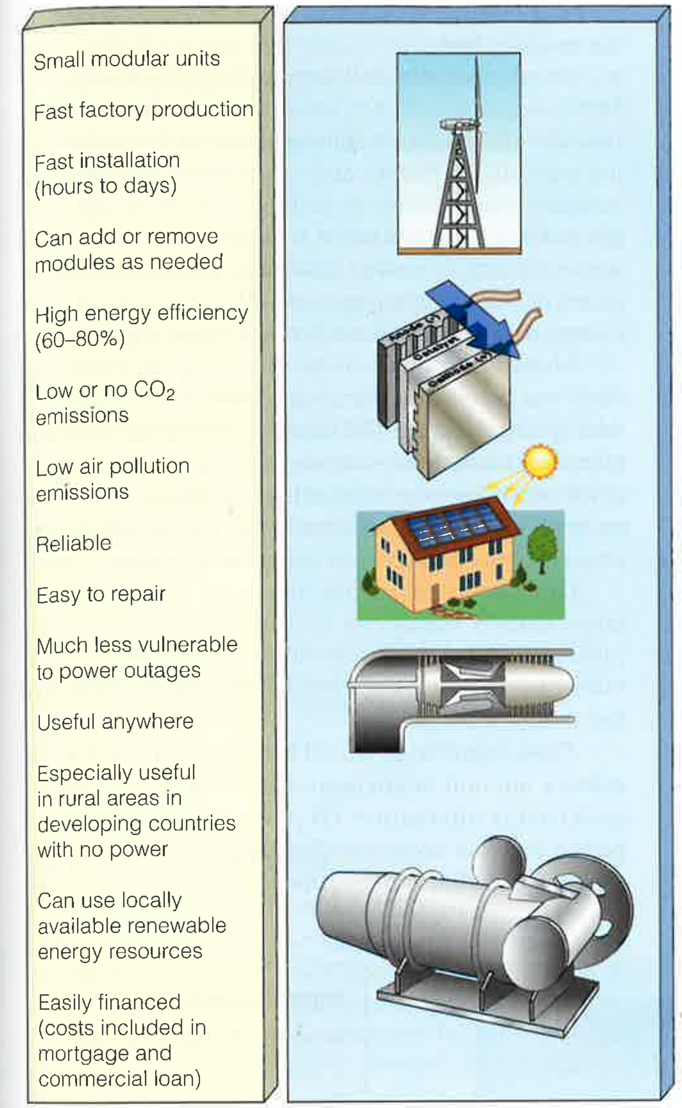


Figure 15-41 Some advantages of micropower systems.

15-10 SOLUTIONS: A SUSTAINABLE ENERGY STRATEGY

What Are the Best Energy Alternatives? We have a variety of nonrenewable and renewable energy resources, each with certain advantages and disadvantages. Many scientists and energy experts who have evaluated these energy alternatives have come to the following general conclusions:

- *There will be a shift from centralized macropower systems* (Figure 15-39) *to smaller, decentralized micropower systems* (Figures 15-40 and 15-41).
- *The best alternatives are a combination of improved energy efficiency and using natural gas as a fuel to make the transition to increased use of a variety of small-scale, decentralized, locally available renewable energy resources.*
- *Because there is not enough financial capital to develop all energy alternatives, governments and private companies must carefully choose which alternatives to support.*
- *Over the next 50 years the choice is not between using nonrenewable fossil fuels and various types of renewable energy.* Because of their supplies and low prices, fossil fuels will continue to be used in large quantities. The key questions are **(1)** how can we reduce the harmful environmental impacts of widespread fossil fuel use (especially to reduce air pollution and slow projected global warming) and **(2)** what roles can improving energy efficiency and depending more on some forms of renewable energy play in achieving these goals?

What Role Does Economics Play in Energy Resource Use? To most analysts the key to making a shift to more sustainable energy resources and societies is not technology but economics and politics. Governments use three basic economic and political strategies to help stimulate or dampen the short-term and long-term use of a particular energy resource.

The first approach is *allowing all energy resources to compete in a free market without government interference.* Free-market economists believe that letting the marketplace decide is the most effective way to develop future energy alternatives.

However, this is difficult to accomplish because of well-entrenched government intervention into the marketplace in the form of subsidies, taxes, and regulations. Another potential problem is that the emphasis on short-term profits for investors can inhibit development of new energy resources. During their 20- to 40-year development and phase-in period, new energy alternatives can rarely compete economically with established energy resources and face a *chicken-and-egg dilemma*. There must be enough orders for companies to invest in mass production facilities that will bring the price down, but most users will not place orders until the price comes down. Unless private companies invest large amounts of capital in long-term research and development, government support is needed during this period.

However, unless it is hindered by government regulations, private enterprise may accelerate the transition from *centralized macropower systems* to *decentralized micropower systems* because of the potential for huge profits.

The second approach is *trying to keep energy prices artificially low to encourage use of selected energy resources.* This is done mostly by **(1)** providing research and development subsidies and tax breaks and **(2)** enacting regulations that help stimulate the development and use of energy resources receiving such support.

For example, most governments have helped stimulate the development of fossil fuels and nuclear power by supporting research and development, providing

subsides, and enacting favorable regulations for more than 50 years. Since the mid-1970s some governments have also been subsidizing energy efficiency and renewable energy technologies, but usually at much lower rates than fossil fuels and nuclear power.

Critics argue that subsidies and tax breaks do not work because **(1)** they amount to only about 1–2% of the total energy economy and **(2)** after 20 years of government subsidies and tax breaks, solar and wind power provide only about 1% of the energy used in the United States and the world and are too costly.

Supporters of such subsidies, tax breaks, and favorable regulations for energy efficiency and renewable energy resources argue that **(1)** they have not been in place very long compared to those supporting fossil fuels and nuclear energy, and **(2)** they have been too low and too erratic to help these new industries reach a take-off point and achieve lower prices through mass production. For example, subsidies and tax breaks put into place in the mid-1970s for energy conservation and renewable energy in the United States were sharply reduced in the 1980s and early 1990s before being increased somewhat since 1995.

Even with favorable treatment, some energy alternatives (such as nuclear power) may not be able to compete economically (p. 353). Proponents of increased support of renewable energy resources argue that they should be helped to reach the take-off point to find out how well they can compete on their own in the marketplace.

The third approach is *keeping energy prices artificially high to discourage use of an energy resource.* Governments can raise the price of an energy resource by withdrawing existing tax breaks and other subsidies, enacting restrictive regulations, or adding taxes on its use. This **(1)** increases government revenues, **(2)** encourages improvements in energy efficiency, **(3)** reduces dependence on imported energy, and **(4)** decreases use of an energy resource that has a limited future supply.

Many economists favor *increasing taxes on fossil fuels* as a way to reduce air and water pollution and slow global warming. The tax revenues would be used to **(1)** reduce income taxes on wages and profits (Solutions, p. 707), **(2)** improve energy efficiency, **(3)** encourage use of renewable energy resources, and **(4)** provide energy assistance to the poor and lower middle class.

Other analysts criticize this *output approach*, which taxes carbon emissions at the end of the energy pipeline. Instead, they propose an *input approach*, which taxes each unit of energy produced at the beginning of the energy pipeline.

These input taxes would be **(1)** proportional to the relative amount of environmental damage caused by each energy alternative, **(2)** phased in over a 10-year period to avoid economic disruption, and **(3)** adjusted downward as harmful environmental effects decrease.

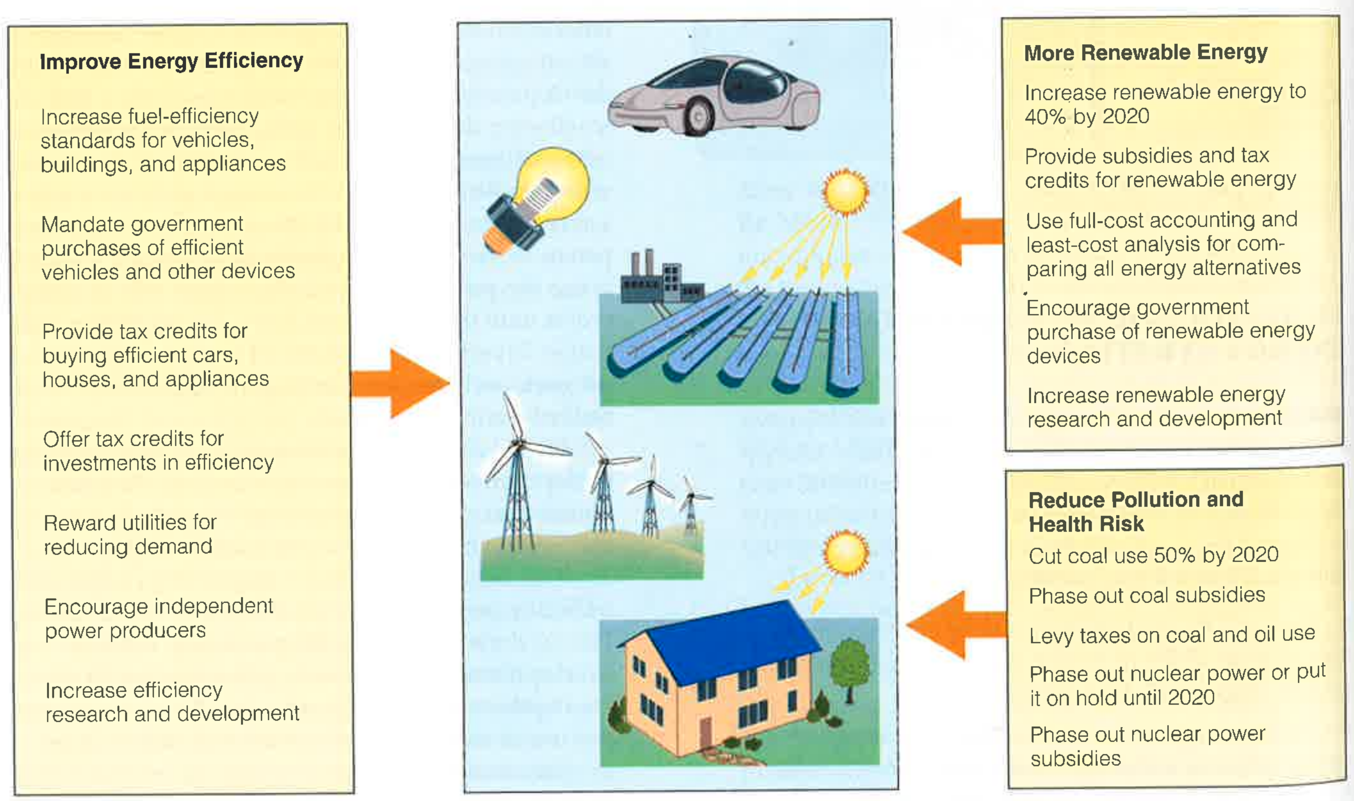


Figure 15-42 Solutions. Suggestions various analysts have made to help make the transition to a more sustainable energy future.

Based on current environmental data, such taxes would be **(1)** zero for energy efficiency, **(2)** fairly low for most forms of renewable energy, **(3)** slightly more for natural gas and more environmentally harmful forms of renewable energy, and **(4)** highest for nonrenewable oil, coal, and nuclear power.

How Can We Develop a More Sustainable Energy Future? Figure 15-42 lists a variety of strategies analysts have suggested for making the transition to a more sustainable energy future over the next few decades.

Energy experts estimate that implementing policies such as those shown in Figure 15-42 over the next 20–30 years could **(1)** save money, **(2)** create a net gain in jobs, **(3)** reduce greenhouse gas emissions, and **(4)** sharply reduce air and water pollution. Some actions you can take to promote a more sustainable energy future are listed in Appendix 6.

The move to micropower may accelerate the evolution to a carbon-free hydrogen economy, as proliferating fuel cells create a growing demand for hydrogen as an energy carrier.

SETH DUNN AND CHRISTOPHER FLAVIN

REVIEW QUESTIONS

1. Define the boldfaced terms in this chapter.
2. What is *energy efficiency*? How much of the energy used in the United States is wasted? What percentage of this is wasted because of the second law of energy, and what percentage is wasted unnecessarily? What is *life cycle cost*? What are three of the least efficient energy-using devices?
3. Explain why we cannot recycle energy. List three ways to slow down the flow of heat from **(a)** a house and **(b)** an office building.
4. What are the advantages of saving energy?
5. What is *cogeneration*, and how efficient is it compared with producing electricity by a conventional coal-burning or nuclear power plant? List two other ways to save energy in industry.
6. What do most experts believe is the best way to save energy in transportation?
7. List the pros and cons of using **(a)** battery-powered electric cars, **(b)** hybrid cars, **(c)** fuel-cell cars, and **(d)** electric bicycles.
8. Describe how we can save energy in homes by using **(a)** superinsulated houses and **(b)** strawbale houses. What are the four most efficient ways to heat a house? Describe ways to make an existing house more energy efficient. What are the most efficient and least efficient ways to heat water for washing and bathing? List the pros and cons of switching from inefficient incandescent and halogen light bulbs to efficient compact fluorescent light bulbs.
9. Describe how the internet can save energy and help reduce carbon dioxide emissions.
10. List three reasons why there is little emphasis on saving energy in the United States, despite its important benefits.
11. What are the major advantages and disadvantages of relying more on direct and indirect renewable energy from the sun?
12. Distinguish between a *passive solar heating system* and an *active solar heating system* and list the pros and cons of each system.
13. Describe three ways to cool houses naturally.
14. Distinguish between the following solar systems used to generate high-temperature heat and electricity: **(a)** power tower, **(b)** solar thermal plant, **(c)** parabolic dish collection system, **(d)** nonimaging optical solar concentrator, and **(e)** solar stoves. List the advantages and disadvantages of concentrating solar energy to produce high-temperature heat or electricity.
15. What is a *solar cell*? List the advantages and disadvantages of using solar cells to produce electricity.
16. Distinguish between *large-scale hydropower*, *small-scale-hydropower*, and *pumped-storage hydropower* systems. List the advantages and disadvantages of using hydropower to produce electricity.
17. List the advantages and disadvantages of using the following systems for storing heat in water to produce electricity: **(a)** ocean thermal energy conversion (OTEC), **(b)** saline solar ponds, and **(c)** freshwater solar ponds.
18. List the advantages and disadvantages of using wind to produce electricity. What parts of the world have the greatest potential for using wind resources?
19. List the advantages and disadvantages of **(a)** burning solid biomass as a source of energy and **(b)** producing gaseous and liquid fuels from solid biomass.
20. What is the *solar-hydrogen revolution*? Describe seven ways to produce hydrogen and five ways to store hydrogen. What is a *fuel cell*, and what are the advantages and disadvantages of using this technology? List the advantages and disadvantages of using hydrogen as a source of energy.
21. What is *geothermal energy*? Describe three types of geothermal reservoirs. List the advantages and disadvantages of using geothermal energy to produce heat and electricity.
22. What is *micropower*, and what are its advantages over macropower electricity systems? Describe five types of micropower systems.
23. What four conclusions have energy experts reached about possible future energy alternatives?
24. Summarize the three different economic approaches that can be used to stimulate or dampen the use of a particular energy resource. List the pros and cons of each approach.
25. What are major ways to help make the transition to a more sustainable energy future?

CRITICAL THINKING

1. A homebuilder installs electric baseboard heat and claims that "it's the cheapest and cleanest way to go." Apply your understanding of the second law of energy (thermodynamics) to evaluate his claim.

2. Someone tells you that we can save energy by recycling it. How would you respond?

3. Should the Corporate Average Fuel Economy (CAFE) standards for motor vehicles used in the United States be increased, left at 1985 levels (the current situation), or eliminated? Explain. Should the CAFE standards for light trucks, vans, and sport utility vehicles be increased to the same level as for cars? Explain. List the positive and negative effects on your health and lifestyle if CAFE standards are **(a)** increased or **(b)** eliminated.

4. What are the five most important things an individual can do to save energy at home and in transportation (see Appendix 6)? Which, if any, of these do you currently do? Which, if any, do you plan to do?

5. Congratulations. You have just won $150,000 to build a house of your choice anywhere in the country. What type of house would you build? Where would you locate it? What types of materials would you use? What types of materials would you *not* use? How would you heat and cool your house? How would you heat your water? Considering fuel and energy efficiency, what sort of lighting, stove, refrigerator, washer, and dryer would you use? Which of these appliances could you do without?

6. Explain why you agree or disagree with the following proposals by various energy analysts: **(a)** Federal subsidies for all energy alternatives should be eliminated so that all energy choices can compete in a true free-market system, **(b)** all government tax breaks and other subsidies for conventional fuels (oil, natural gas, coal), synthetic natural gas and oil, and nuclear power (fission and fusion) should be removed and replaced with subsidies and tax breaks for improving energy efficiency and developing solar, wind, geothermal, and biomass energy alternatives, and **(c)** development of solar and wind energy should be left to private enterprise and receive little or no help from the federal government, but nuclear energy and fossil fuels should continue to receive large federal subsidies.

7. Explain why you agree or disagree with the proposals suggested in Figure 15-42 (p. 392) as ways to promote a more sustainable energy future.

8. Congratulations. You have just been put in charge of the world. List the five most important features of your energy policy.

PROJECTS

1. Make a study of energy use in your school and use the findings to develop an energy-efficiency improvement program. Present your plan to school officials.

2. Learn how easy it is to produce hydrogen gas from water using a battery, some wire for two electrodes, and a dish of water. Hook a wire to each of the poles of the battery, immerse the electrodes in the water, and observe bubbles of hydrogen gas being produced at the negative electrode and bubbles of oxygen at the positive electrode. Carefully add a small amount of battery acid to the water and notice that this increases the rate of hydrogen production.

3. Use the library or the internet to find bibliographic information about *Amory Lovins*, *Seth Dunn*, and *Christopher Flavin*, whose quotes appear at the beginning and end of this chapter.

4. Make a concept map of this chapter's major ideas, using the section heads and subheads and the key terms (in boldface). Look at the inside back cover and on the website for this book for information about making concept maps.

INTERNET STUDY RESOURCES AND RESOURCES FOR FURTHER READING AND RESEARCH

The website for this book contains helpful study aids and many ideas for further reading and research. Log on to:

http://www.brookscole.com/product/0534376975s

and click on the Chapter-by-Chapter area. Choose Chapter 15 and select a resource:

- "Flash Cards" allows you to test your mastery of the Terms and Concepts to Remember for this chapter.
- "Tutorial Quizzes" provides a multiple-choice practice quiz.
- "Student Guide to InfoTrac" will lead you to Critical Thinking Projects that use InfoTrac College Edition as a research tool.
- "References" lists the major books and articles consulted in writing this chapter.
- "Hypercontents" takes you to an extensive list of sites with news, research, and images related to individual sections of the chapter.

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Bond, M. 2000. Solar energy: seeing the light (industry overview). *Geographical* vol. 72, no. 11, pp. 28–31. (subject guide: solar energy)

PART IV

ENVIRONMENTAL QUALITY AND POLLUTION

In our every deliberation, we must consider the impact of our decisions on the next seven generations.

IROQUOIS CONFEDERATION, 18TH CENTURY